High Lights

Two-Pole Generators. The unequal mechanical rigidity of the rotor body on the two major axes and unequal magnetic forces on any two major axes of the stator core produce vibrations in two-pole generators that become of increasing importance in 3,600-rpm units of relatively large capacity; the disturbing force may be eliminated or the vibration restricted to isolated parts (*Transactions pages 30–4*). Critical speeds of rotors may be predetermined analytically and stresses determined by the photoelastic method; control of bearing lubrication promises increased efficiency (*Transactions pages 51–6*).

Winter Convention. More than 80 technical papers are scheduled for presentation in the 18 technical sessions and 9 conferences of the AIEE winter convention, to be held January 22–26, 1940, at New York, N. Y. Presentation of the Edison and Hoover Medals, and of the Alfred Noble prize, a popular demonstration lecture, the annual smoker and dinner-dance, and an unusual group of inspection trips are other features of the convention (*pages 37–41*).

Insulation Research. Continuing its unique position of effectively bringing together both scientific and "practical" groups interested in the general subject of electrical insulation, the Conference on Electrical Insulation of National Research Council recently held its 12th annual meeting. The 26 progress reports presented at its four technical sessions reflected the latest advances in insulation research (*pages 33–6*).

Power Generation. The use of 3,600-rpm high-pressure high-temperature hydrogen-cooled turbine-generator units of large size is the most important advance in electric-power generation during the past six years, according to the current progress report of the AIEE committee on power generation. In the hydroelectric field, activity has centered largely in governmental projects (*pages 12–22*).

Electrical Insulation. Those who have not had an opportunity to follow closely the progress in the field of electrical insulation, but who would like to obtain a general view of the present status of the art, may be interested in a review of the advancements achieved by the physicist, the chemist, and the electrical engineer—the triple alliance in electrical insulation (*pages 23–32*).

Section Activities. In recognition of effective services to the Institute, the AIEE national membership committee lists in this issue the personnel of the membership committees of all 67 of the Institute's local Sections (*pages 52–3*). Some of the current activities reported by the various Sections are reviewed by a member of the Sections committee (*page 51*).

Transcontinental Telephony. "In its journey during the last quarter of a century telephony has crossed several thresholds, but, even so, the journey may be in its early stages," says a noted AIEE past president in reviewing the progress achieved since 1914 when the first transcontinental telephone conversation transpired (*pages 3–11*).

Machine-Tool Equipment. Electrical equipment for machine tools has helped improve the performance of the tools, but motors and control devices should have greater reliability and be more suitable for application on different voltages and frequencies in order to compete with mechanical and hydraulic control (*Transactions pages 18–24*).

Air Circuit Breakers. Development of air circuit breakers has paralleled the growth of power systems since the first knife-switch device was used about 1885. Modern low-voltage air circuit breakers with a new type of arc interrupter have interrupting ratings up to 80,000 amperes at 600 volts alternating current (*Transactions pages 24–30*).

Hydrogen-Cooled Generators. Hydrogen offers several advantages as a cooling medium as compared with air in electrical machines, and is used in many generators operating at 3,600 rpm. Suitable shaft seals, cooling means, and control system for gas must be provided (*Transactions pages 11–17; 35–50*).

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Carrier-Current Losses. The carrier-current channel for supervisory control on the Boulder Dam-Los Angeles transmission lines was found to have higher than calculated losses, and to require special circuit designs to suppress interference from static, corona, and arcs (*Transactions pages 4–10*).

D-C Amplifier. A high-gain d-c amplifier for recording nonrecurrent biologic phenomena on a cathode-ray tube, using radio-receiver-type components, has a maximum voltage amplification of 6×10^4, and requires only moderate battery voltages (*Transactions pages 60–4*).

Turbine-Electric Drive. A form of drive in which a steam turbine is coupled both mechanically and electrically to a textile "range," or group of co-ordinated machines, provides variable speed and flexibility (*Transactions pages 57–60*).

Textile Machinery. Tests have been made to establish the characteristic power requirements and derive an empirical formula for horsepower for spinning machines (*Transactions pages 1–4*).

Coming Soon. Among special articles and technical papers now undergoing preparation for early publication are: an article embracing the essential substance of the lecture on atomic disintegration to be delivered at the AIEE 1940 winter convention by Nobel Prize Winner Enrico Fermi; an article tracing recent trends in steel-mill electrification by A. F. Kenyon (A'24); an article discussing the role of science in the electrical industry by M. W. Smith (M'36); a paper continuing a series of reports of a lightning investigation on transmission lines by W. W. Lewis (F'38) and C. M. Foust (M'31); a paper on the transformation theory of general static polyphase networks by L. A. Pipes (A'37); a paper describing methods of sensitive ground protection for radial distribution feeders by L. F. Hunt (F'38) and J. H. Vivian (A'34); a paper discussing the anomalous behavior of the moving systems of single-phase a-c watt-hour meters at no load by F. C. Holtz (M'25); a paper describing the testing of distribution arresters by Herman Halperin (M'26); a paper on surge-voltage breakdown characteristics for electrical gaps in oil by R. W. Sorensen (F'19); a paper describing capacitor relay timing in industrial control by Carroll Stansbury (F'38) and T. B. Jochem (A'32); a paper on the high-capacity "hydro-blast" circuit breaker for central-station service by W. F. Skeats (M'36) and W. R. Saylor (A'38); a paper describing a new time standard by H. E. Warren (A'02); and a paper on the transient and steady-state performance of potential devices by E. L. Harder (A'30), P. O. Langguth (A'28), and C. A. Woods, Jr. (A'37).

Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London).

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A Quarter Century of Transcontinental Telephony

A review of the significant developments in long-distance telephony since the first transcontinental telephone conversation in 1914

FRANK B. JEWETT
FELLOW AIEE

AS A TOPIC I have chosen the epoch of transcontinental telephony because it was 25 years ago last July that the first transcontinental circuit carried its first conversation, and it is 25 years ago this January that the first transcontinental line, which consisted of three circuits, was opened for public use. My choice, however, is based upon much more than a mere desire to commemorate a now far-off event, propitious though such a gesture may be. I hope that I can portray this early telephone line for what it was in fact—the progenitor of much that has taken place in the last 25 years in a very active sector of electrical engineering. It marked the dawn of a new era in electrical communication.

As we review the history of this period, we witness new physical appliances recasting not only the technological side of a business but its traffic and commercial aspects as well. I hope to make clear the interplay of technological and economic factors over a considerable period of time to the end that copper and iron in huge quantities have been replaced by minute electron streams *in vacuo;* further that the attenuation of telephone currents, once the epitome of the telephone engineer's troubles, can now be pushed to levels hundreds of times higher than the early limit before it becomes comparable with the other economic factors involved.

In any general survey of the changes and improvements that have altered the art of telephony during a period of time or have stemmed from the successful solution of a specific problem, one must always have in mind the ultimate objective of commercial telephony. This objective is simply stated; the attainment of it, even approximately, is by a long hard road. From the day when men of vision realized the potential possibilities of Bell's invention, the ultimate technical objective has been a service at once so extensive and adequate that anyone, anywhere, at any time, and on demand could talk to anyone, anywhere else, with ease and clarity. Added to this has always been the economic and social objective of a cost so low as to offer no substantial bar to an essentially untrammeled use of telephony by anyone who has occasion to talk with another at a distance.

For the Bell System as a public service agency, all this is succinctly stated in the frequently quoted objective of the best possible service at the lowest possible cost consistent with financial stability and fair treatment of employees. When, however, one attempts to translate this broad objective into the concrete technical terms needed for its fulfillment, the phraseology is quite different.

For the research man and the engineer, the goal is one compounded of a transmission art so perfect that distance per se is no barrier; that telephone circuits and all they require in auxiliary apparatus for proper operation can be produced so cheaply as to be available in the profligate numbers required for a universal no-delay service; and, finally, that the vast society of Lilliputian currents must live amicably with each other tightly packed together in a world of Brobdingnagian interference.

It is a distant goal even when viewed through the glasses of perfection that picture direct circuits for every desired connection. It is doubly distant when their practical senses tell the scientist and engineer that they must attain part of the solution with indirect switched circuits and, further, that these switches must neither delay the service nor affect its quality appreciably.

The goal of perfection is still ahead, but we have made astonishing progress toward it in the quarter century since the first voice spanned the continent. In very large measure this progress is directly the result of developing fully the latent possibilities of the physical instrumentalities unearthed in the search for an answer to transcontinental telephony. There may seem to be little connection between the quest for an amplifying device to solve a specific transmission problem in 1914 and an engineering study in 1939 to work out a nationwide traffic-routing system, and yet one is the direct lineal descendant of the other.

Visualizing the Telephone Network

In considering the evolution of telephony, we are dealing with a structure that does not lend itself to pictorial representation. But if the reader could be transported rapidly, magic-carpet-wise, out across the continent 3,000 miles or so, thus enabling him to visualize what a complex thing is this creation we are considering, he might acquire at least a superficial conception of its elaborateness and seeming fragility. Only in this way would he fully sense how remarkable it is that this far-flung and delicate structure

Essential substance of the Thirteenth Steinmetz Memorial Lecture delivered under auspices of the Steinmetz Memorial Foundation at a meeting of the AIEE Schenectady (N. Y.) Section, November 2, 1939.

should be endowed with surprising electrical stability and immunity to meteorological and man-made interference.

Let us imagine at the outset a single pair of wires extending out the window and thence across-country for hundreds or even thousands of miles, and let us bear in mind that these wires by virtue of their length have become possessed of considerable amounts of distributed capacitance, inductance, and leakage—and are, in addition, subject to a variety of induction effects from paralleling communication and power circuits.

Moreover, in many instances this pair of wire is packed tightly together with many similar pairs and enveloped in an impervious lead sheath to form a cable in which a neutral gas, such as nitrogen, is maintained under pressure, and which, should a leak in the sheath develop, operates an alarm circuit to sound a distant SOS. We must also note the presence on many of the pairs of loading coils spaced at regular intervals varying from about $^5/_8$ mile to $1^1/_8$ miles, depending on the type of cable. Each loading coil is a winding of wire on a special magnetic core. Its function is to assist the speech currents, as they travel, to overcome the large attenuating effect of the electrostatic capacitance of the tightly packed wires. These coils, of which as many as 2,000 or 3,000 may be called into play in the handling of a single message, must be electrically identical to a very high degree. Next, there is the repeated and uniform twisting of each pair of wires at its own particular pitch to secure such nicety of balance, both electrostatic and electromagnetic, that not more than a millionth of the power of a telephone circuit will pass over inductively to any neighboring circuit. Then at intervals of 50 miles for certain types of cables, and at shorter intervals—even as low as 5 miles—on certain newly projected types, we would find thermionic amplifiers which restore the message energy after attenuation by resistance and other forms of dissipation. Closely associated with some of these amplifiers are other devices which suppress electric echoes or which automatically counteract the effect of changes in conductor resistance induced by changes in temperature.

The Fundamental Requirement an Amplifier

Many of the features of a long telephone line just enumerated are comparatively recent accomplishments; they project me somewhat ahead of my story. We must return to the year 1914, when a long-distance telephone line consisted of a pair of large copper wires strung in the open and with magnetic loading coils spaced along it at intervals of eight miles. The day of speech current amplifiers had not arrived except for a carbon microphone type which because of distortion was applicable only as a single-stage amplifier on nonloaded lines. Every long circuit operated essentially upon the basis that no energy came out at the receiving end that was not introduced at the sending end—and, needless to say, very little of that. It was also necessary to preserve enough of the energy at the various frequencies represented in speech so that intelligibility was not sacrificed—a requirement that added appreciably to the problem. With the use of eight-gauge hard-drawn copper line wires (weighing 870 pounds to the loop mile) augmented by loading, it was just possible to carry on a conversation between New York, N. Y., and Denver, Colo. How slight the margin of safety was in that line is well illustrated by the fact that it had an equivalent loss of about 35 decibels, so that the power at the receiver amounted to only about 1/4,000 of the power sent out by the transmitter. On this same basis a telephone line spanning the continent would have yielded only 1/400,000 of the power applied to it at the transmitter.

A comparison of these two figures shows at once that there was no hope of solving the problem of transcontinental telephony by some scheme that would apply to the circuit a larger power than the typical telephone transmitter. Any feasible solution must necessarily involve some sort of current rejuvenation at several points intermediate between transmitter and receiver, since the use of heavier copper was economically unsound; in other words, tandem amplification with all its obvious difficulties was the only way out. The search for a successful amplifier or repeater extended over years, and almost simultaneously three promising devices were brought to the point of trial: One, an improvement of that already mentioned, was a mechanical structure that used the amplifying property of the carbon microphone; one a low-pressure arc which possessed a negative resistance characteristic; and, finally, one that employed an electronic current controlled electrostatically by a grid of metal wires placed athwart it. This third arrangement obviously was derived from the audion of Lee deForest, which he was then using to receive radio signals.

To those who were concerned with the problem of the telephone repeater at that time, it was far from evident which of the three alternatives would ultimately win in the struggle for existence. However, the answer was not long in revealing itself. The behavior in practical tests of the electronic vacuum tube designed especially as a telephone amplifier left no doubt that it was at once satisfying in its then performance and full of promise as to additional applications in the future. As we look back upon that situation in the light of our present knowledge, perhaps our wonder is that so recently the ubiquitousness of the vacuum tube should have lain unrevealed.

Laboratory Techniques

We must bear in mind, however, that it employed a high vacuum and that pumps for creating such, even within the physics laboratory, were but lately introduced; moreover, that it also contained a fragile filament—sometimes coated and sometimes metallic—which served as electron emitter and which was subject to little understood vagaries. The making of vacuum tubes, far from being a factory process, called for the skill and personal supervision of the laboratory; and even after this bestowal of care the filament might fail in a few hours or a minute leak might destroy the vacuum and thus end the life of a device upon the making of which many anxious hours had been expended and on whose reliability the integrity of service depended.

I realize that these few words will give but a very im-

perfect picture of the task confronting those who undertook to adapt deForest's audion to the work of the telephone repeater. Unless one has tried with a molecular pump (so-called) and a liquid air and charcoal combination, and aided by baking and bombardment, to drive a seemingly endless amount of gas out of glass walls and metal plates and grids of a tube, and yet leave the activity of the filament coating unimpaired, he can scarcely realize the hurdle the telephone engineers of nearly 30 years ago had undertaken to clear. And suppose an experimental line were to prove workable, what chance would there be, considering the highly personalized production techniques and the final fragile character of the vacuum tube as then constructed, that the line could ever be more than an unreliable appendage to a network of shorter circuits?

To those as familiar with sturdy vacuum tubes as with incandescent lamp bulbs, it becomes impossible to recount

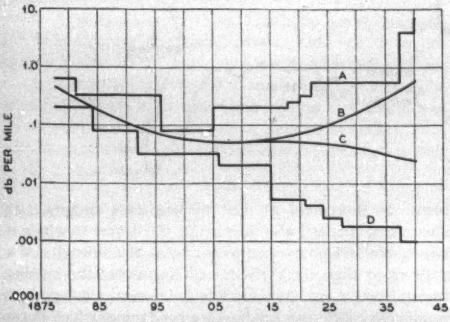

Figure 1. Attenuation loss in long-distance telephone lines

Curve *A* is for circuits having the highest attenuation per mile, the extreme for 1940 represents the coaxial cable now being installed

Curve *B* is the average for all lines, without repeaters

Curve *C* is the over-all average for all lines, including repeaters

Curve *D* is for circuits having the lowest attenuation per mile after repeaters have been taken into account

25 years' progress step by step with the intention of finally revealing the present status in climactic fashion. Instead, my objective will be, by dealing in engineering values, to bring out the interplay of the more significant factors, tracing the line of development and argument that has completely remade the technique and the instrumentalities of long-distance telephony.

A Changing Point of View

The advent of the vacuum-tube amplifier radically changed the point of view of the engineer regarding long-distance telephone lines. Over a period of years he switched from a policy of extreme parsimony to one almost of prodigality. Where initially his every thought had been to design lines so as to minimize the possibility of energy loss at every point, he later chose smaller and smaller line wires deliberately because the saving on copper more than compensated for the additional amplification entailed. Figure 1 may be of interest in this connection. Curve *B* shows that during the period from 1880 to 1915 the average loss per mile fell, the reason being that heavier and heavier copper was resorted to. Then, in 1915, with the advent of repeaters, the circuit attenuation began to mount since lighter copper and higher frequencies could be employed. On the other hand, the over-all loss including repeaters (curve *C*) still continues to decline.

Prior to the repeater, the loading coil was of paramount importance as a conserver of the power of the telephone currents. As so frequently happens in engineering design, this economy was not always to be obtained without paying a toll. For instance, in the first transcontinental line loading had to be pushed to such a point that a serious degradation of speech quality resulted. The more heavily loaded a telephone line—that is, the larger the inductance of the loading coils associated with it—the narrower becomes the band of frequencies the line can transmit. It was the discovery of this effect of loading that led a few years later to the invention of the electric wave filter. The discovery was made mathematically by Doctor George A. Campbell, who but recently retired from the Bell Telephone Laboratories' staff (*EE Jan. '36, p. 122; Dec. '37, p. 1518*). He it was who saw the possibility of simulating and generalizing the effect of a long telephone line, by lumped inductances, capacitances, etc., to the end that very compact electric wave-filter circuits could be constructed.

First Experimental Line

Returning to the first experimental transcontinental line of 1914, it included three repeater units, placed at Pittsburgh, Pa., Chicago, Ill., and Denver, Colo., respectively. These, when supplemented by very heavy loading, were just sufficient to make the circuit usable. The quality of speech transmitted left much to be desired, however, for the inductance of the loading coils was such that an effective band of speech frequencies only about 900 cycles wide could traverse the line. This is to be contrasted with a band about 2,500 cycles wide handled by ordinary circuits today, while those employed for interconnecting radiobroadcast stations may transmit a band three times this latter figure; and even this is but a fraction of the band of carrier frequencies that a multichannel carrier system will transmit.

The original transcontinental line with but three repeaters was purely experimental. It proved, however, that the country could be spanned telephonically, and it also established the supremacy of the vacuum-tube amplifier as against the arc and the carbon microphone. Shortly after commercial service started in 1915, six repeaters were substituted for the original three, and these were, of course, spaced about as uniformly as the location of cities and towns would permit. The line itself had a loss of about 60 decibels and the repeaters gave a gain of about 40 decibels. Of course, the day of unattended repeaters and automatic gain control was still undreamed

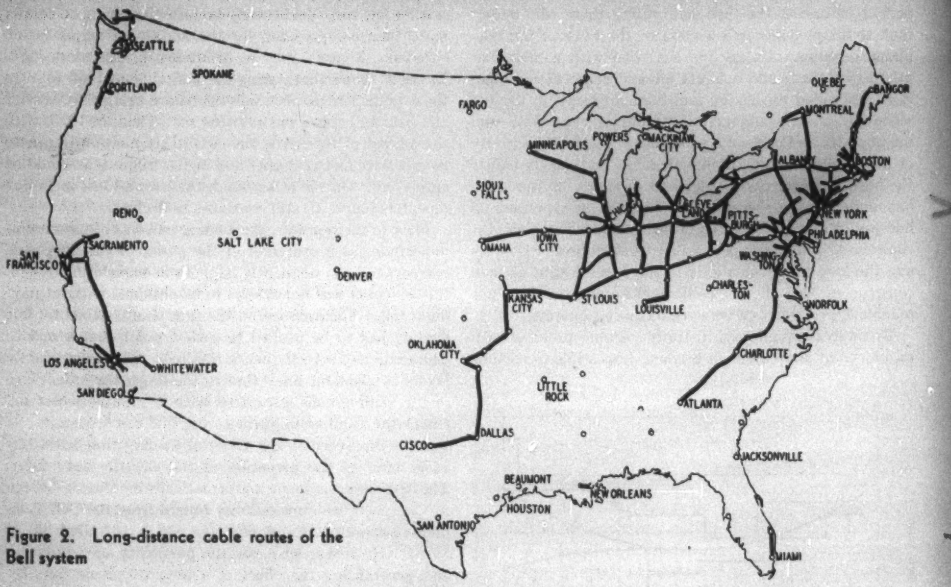

Figure 2. Long-distance cable routes of the Bell system

of. Even with six repeaters it was necessary to retain heavy loading, so that the original line represented about the allowable minimum in commercial speech quality.

The vacuum tube quickly revealed itself to be a fertile subject for research. Over a period of a few years, more efficient and more durable filaments were discovered, and improved assembly methods were devised as well as methods of rapid evacuation. Thus, it became possible, step by step, to be more generous in the use of repeaters in the long-distance telephone plant. The accompanying table traces history from this standpoint. With success accumulating behind us, particularly by way of improved repeaters and enhanced knowledge of how to operate many repeaters in tandem, it was not long before we overhauled the original transcontinental line, removing the loading coils altogether. Thus, the one device which a few years before symbolized long-distance telephony had now begun to slip. Coil removal from the transcontinental line was dictated both by a desire to improve speech quality and to obtain more circuits. The *demand* for service was increasing in response to *improved* service, and removal of the loading introduced the possibility of multiplexing the lines with carrier systems, so where we had originally only three circuits we could now operate nine.

Utility of the Repeater

At the same time, as may be inferred from the table, repeaters were becoming more and more common on circuits of intermediate length. In fact, the importance of the repeater is in considerable part attributable to the changes it has been instrumental in working in the entire toll plant, in short-haul as well as long-haul circuits. As illustrating this and also illustrating the degree to which it has enabled telephone engineers to plan their circuits on a basis other than the early one of conserving the ingoing transmitter energy, I should like to mention a toll project employing cable with small-gauge conductors which dates from about 1920, that is, five years after the initial transcontinental success.

In a cable, because the wires of each pair are close together and therefore have large electrostatic capacitance compared with an open-wire pair, the attenuation is great unless very heavy conductors are employed. Even then the distortion in nonloaded cables is great, and so for many years cable was anathema in toll circuits prior to the repeater. In other words, so long as the initial ingoing energy was all that could be invoked for reproduction of the message at the receiver, cable was generally rejected.

Nevertheless, cable possesses other virtues so obvious that the toll engineer always eyed it with the deepest envy. Circuits in cable are inherently stable because they are protected from atmospheric moisture. They are also less liable to breakage and to inductive disturbances from paralleling circuits, notably power lines. However, the full virtue of a cable is not realized until the density of traffic becomes large enough to require a large group of circuits. A full-sized toll cable, for instance, may contain as many as 300 or

Voice-Frequency Repeaters Installed in Bell System

Year	Total*
1908	16
1910	41
1915	136
1920	1,250
1925	7,500
1930	80,000
1935	102,000
1938	107,000

* As of December 31.

400 separate lines, and as a normal daily message capacity of a single circuit is perhaps 30 to 40, the potential capacity of such a cable is relatively large. It developed, however—and perhaps it was one of those fortunate coincidences—that by the time a cable became feasible from the technical point of view, the demand in the regions of denser population had risen to a height to justify it economically. Omitting reference to an early heavy-wire cable between Boston and Washington, which was operated without repeaters and which was installed because it was deemed important to have unfailing telephone service along this portion of the Atlantic seaboard, the first repeatered cable (and it was therefore one employing relatively small gauges of wire) was placed between New York, N. Y., and Pittsburgh, Pa., with the plan of extending it as need arose to Chicago, Ill., and perhaps to points farther west. The New York-Pittsburgh section was engineered in 1920 and went into service in 1922, seven years after the transcontinental trial had affirmed the value of the repeater. Today, so rapidly has the demand for long-distance telephony grown, that we have not simply a spur of toll cable, but a system which without exaggeration may be referred to as a network. As may be seen from figure 2, it runs from Maine to Georgia and Texas, and as far west as Omaha, Nebr., and Dallas, Tex., and interconnects the important cities of the eastern half of the United States.

Toll-Cable Attenuation

It might be interesting to digress for a moment at this point, so that we can see how far we have progressed over a period of 25 years in the attack upon attenuation. As mentioned before, the original transcontinental line had an attenuation of 60 decibels, of which about 40 decibels was neutralized by six repeaters. Large line wires and loading coils were employed to minimize the part to be played by the amplifying elements in the circuits. How vastly different the situation is today. The attenuation of a cable circuit connecting New York and Pittsburgh is 200 decibels, while for one connecting Boston and Dallas it is 1,100 decibels. To write these results in the form of fractions gives, for the first, 10^{-20}; and the second 10^{-110}. In other words, a telephone message in traveling from Boston to Dallas must receive a 10^{110}-fold amplification in order that it may be compensated against the incursions of attenuation. If this enormous amplification all had to be applied at the sending end of the circuit, there probably would not be enough energy in all the coal reserves of the earth to do the trick. Success lies in doing a little bit at a time, for between Boston and Dallas there are some 45 repeater points (the precise number depending upon the routing) and the average gain of a single repeater is about 23 decibels, or about 200-fold on an energy basis.

Such figures as I have just cited, however, are mere child's play nowadays. There is adequate justification in numerous instances for undertaking the multiplexing of cable circuits by the carrier principle. Not only does such an arrangement effect further economies in copper and lead, but what is perhaps more important, the transmission

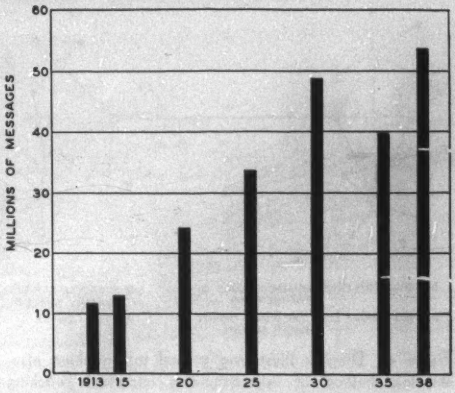

Figure 3. Growth of long-distance telephone traffic

of the high frequencies of carrier systems involves the removal of all loading coils. This, to be sure, causes the attenuation to mount, but a compensating gain appears in reduced time of transmission. Loaded cable circuits possess a relatively slow speed of propagation—perhaps 10,000 to 20,000 miles per second—with the result that for the longer circuits, the echo which returns to the speaker from the far end of the cable lags sufficiently in time to be extremely disturbing. To avoid the echo difficulty, the longer loaded cable circuits are equipped with so-called echo suppressors which operate to permit propagation in only one direction at a time, and are controlled, of course, by the person who first starts talking after any pause. But with nonloaded cable circuits, including all equipment, the speed of propagation jumps to around 100,000 miles per second—more than half the speed of light in free space—with the result that except on extremely long circuits the echo is not separable by the ear from the inducing sound.

But what of the attenuation? It seemed high enough on *loaded* cables. It naturally jumps manyfold, but not more than the capacity of repeaters to counteract. Circuits are in daily use in which the attenuation is as much as 2,400 decibels, and experimental lines have been formed and operated by the looping back and forth of several cable pairs to build up the equivalent of an 8,000-mile straightaway whose total attenuation was about 12,000 decibels. Such a circuit needs a total amplification on an energy basis, amounting to $10^{1,200}$, a ratio so enormous that it quite transcends ratios such as the size of the total universe to the size of the smallest known particle of matter.

Naturally, the problem of balancing this huge amplification against the correspondingly huge loss to the required precision, one or two decibels, is difficult. Fortunately, a new form of amplifier employing the principle of negative feedback was invented by H. S. Black of the Bell Telephone Laboratories, which has enabled us to solve the problem. By using Black's negative feedback we are in possession of amplifiers giving 50 to 60 decibels gain with a

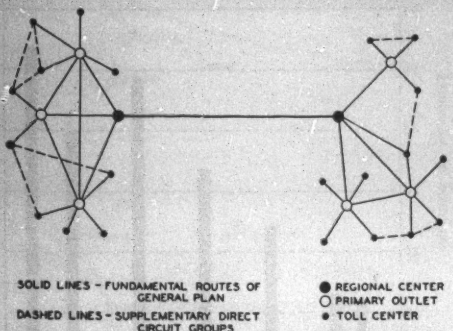
SOLID LINES - FUNDAMENTAL ROUTES OF GENERAL PLAN
DASHED LINES - SUPPLEMENTARY DIRECT CIRCUIT GROUPS
REGIONAL CENTER
PRIMARY OUTLET
TOLL CENTER

Figure 4. Diagram illustrating general toll-switching plan, showing method of interconnecting important switching offices throughout Bell system

variation of not more than 0.01 decibel with normal battery and tube variations. I might also say that were it not for such a repeater, the coaxial type of cable, which again possesses attenuation of the order we are now considering, would be quite impracticable. Time will permit me to do no more than mention in passing the fact that those large gains must be controlled automatically, particularly in response to temperature changes. Cable circuits, by their nature, show only minor variations in capacitance, inductance, and leakage, but the resistance of their conductors can change by large amounts from winter to summer, and even from hour to hour. These changes are more rapid in overhead cables than in those placed underground. However, automatic regulators, which take their cue from so-called pilot wires running through the cable along with the speech pairs, are necessary in both. Thus, the annual variation of attenuation in a cable circuit may be as much as 100 decibels, or more than the entire attenuation of the first transcontinental line. In fact, the variation experienced on some of the long carrier channels is as great as 250 decibels.

Awakening of Public Demand

With the introduction of toll cable together with carrier systems for both open-wire and cable circuits, there was a steady and supporting growth in the demand for long-distance telephone service. Figure 3 shows how rapidly toll traffic has grown. Over the period of the last 25 years, the American public truly seems to have become long-distance-minded. This illustrates what, to my mind, is one of the important principles of engineering that we see exemplified in many lines of industry, namely, that the volume of demand is governed by a complex assemblage of such factors as cost, convenience, and ready availability. Unquestionably the most important factors stimulating growth in demand for long-distance telephone service have been increased convenience, reliability, speed of service, and quality of speech reproduction.

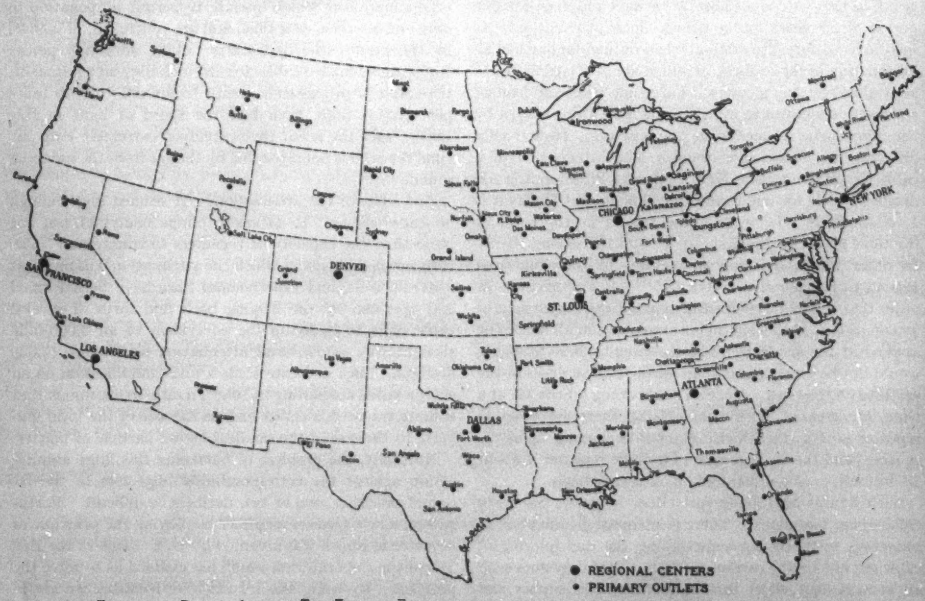

Figure 5. Regional centers and primary outlets of the Bell system in the United States and Canada

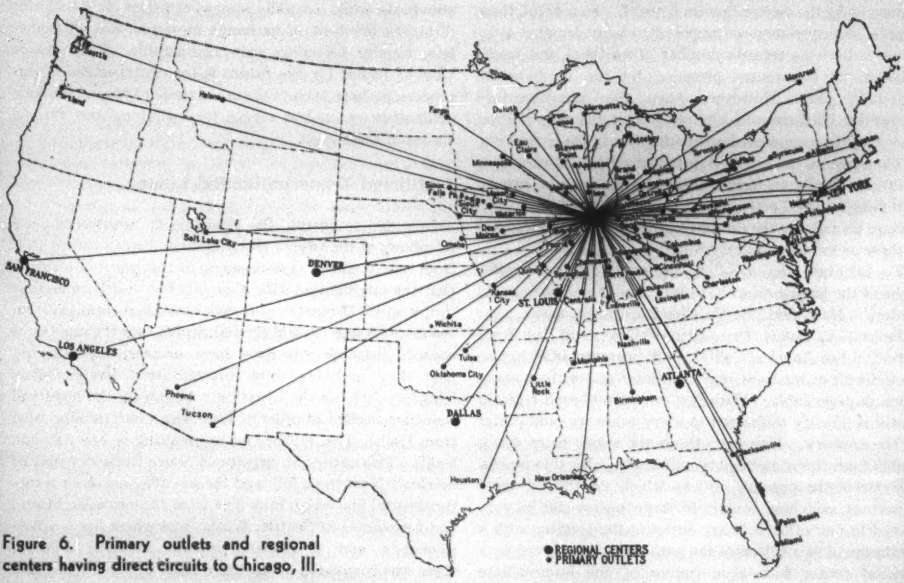

Figure 6. Primary outlets and regional centers having direct circuits to Chicago, Ill.

Our chief objective, of course, in providing more circuits of adequate transmission efficiency has been to cut to a minimum the delay the calling subscriber experiences before reaching his called party, thus increasing the value of the service and incidentally inducing him to use more of it, a result which in turn makes additional circuits necessary. This to-and-fro process has been influenced by periodic reductions in rates as improved facilities and a larger density of traffic have permitted. Nor should I fail to mention that one of the most important factors in this "chain reaction" has involved the development of superior operating techniques and more direct-circuit routings which have been of assistance in enabling the operators to reach distant points quickly.

These considerations lead to a discussion of what we call a general toll-switching plan. It is quite apparent that when the art has reached a point where seconds count in completing calls, very careful study indeed must be given to the question of where unnecessary seconds can be clipped from our operating times. Such a study must be nationwide, for it must give attention to the calls that pass between far corners of the country as well as to those that flow over the heavy-trade routes. At the same time, it is equally obvious that the solution does not lie in direct circuits from each exchange to every other exchange. Such an arrangement would be too profligate and unwieldy to be commercial. However, due weight must be given to the fact that the toll business has shown a more rapid growth over the longer distances than over the shorter ones.

All measures of the quality of service—speed, accuracy, and transmission—show that the difficulty of giving satisfactory service increases rapidly with the number of intermediate switches. The general toll-switching plan, therefore, involves the layout of toll circuits in such manner as to limit as much as practicable the number of switches required to connect any two telephones, and also the establishment of standards of design and construction giving satisfactory transmission over any route thus established.

Toll-Switching Plan

The general features of the plan may be understood by reference to figure 4, which shows the application to a limited operating area such, for example, as a region of the United States. Within the area are selected a small number of important switching points designated as "primary outlets." Each toll center is connected directly to at least one of these outlets and all primary outlets within the area are directly interconnected. This makes possible the interconnection of any two toll centers within the area with a maximum of two switches and within the part of the area served by one primary outlet, with a maximum of one intermediate switch.

The primary outlets have been selected after a careful study of the switching and operating conditions and the probable development of toll traffic within the various areas with a view to obtaining the minimum number of primary outlets capable of handling the traffic economically. The routings provided by the plan are supplemented by direct circuits, or by other routings where the amount of business justifies such additional circuits as

indicated by the dashed lines in figure 4. In general, these supplementary routes are required to be at least as satisfactory, both as regards number of switches and transmission, as the routes provided by the fundamental switching plan. However, when the supplementary routes are used only as alternates to a primary routing they may be somewhat less satisfactory in these respects.

The nationwide array of primary outlets is shown in figure 5. We have found it practicable to take care of switching for the 2,500 toll centers of the United States and eastern Canada by the establishment of approximately 150 of these as primary outlets.

To facilitate the handling of longer-distance traffic, eight of the largest cities have been designated as regional centers: New York, N. Y., Chicago, Ill., St. Louis, Mo., Atlanta, Ga., Dallas, Tex., Denver, Colo., and San Francisco and Los Angeles, Calif. Each primary outlet is connected with at least one regional center and with as many more as practicable. With few exceptions, each regional center is directly connected to every other regional center in the country. However, there are many more direct routes than this statement would imply. By this means, any one of the primary outlets, which are the 150 most important switching centers in the country, can be connected to any other primary outlet in the country with a maximum of two switches, and within the area served by a regional center with a maximum of one intermediate switch. As an illustration of the concentration of switching that results, New York serves as regional center for the entire northeastern United States and eastern Canada.

Figure 6 shows the direct circuits radiating from Chicago. As may be noted, several important cities in the Mountain States other than Denver have direct lines to Chicago. Furthermore, some cities in the South can be reached without a switch at Atlanta.

One possible ultimate development would be the increasing connection of primary outlets to a single regional center so that ultimately only one regional center would be necessary. If this were to take place, the regional center would undoubtedly be Chicago. As shown by figure 6, over one-half of the primary outlets already have direct connection with that center.

Future growth will doubtless lead to an increase in the number of toll centers connected directly to a regional center. By this process there would be a continued growth in the number of toll centers that can be interconnected with a maximum of two intermediate switches.

Looking to the future, an increasing amount of the outgoing traffic will be handled by operators in the local central offices, reaching the toll line over toll tandem trunks. It is evident, however, that the ultimate solution of the problem will involve the use of machine methods for the selection of the toll line by the operators, as is now done in certain segregated toll tandem systems.

The entire trend of recent years is thus to decrease the differences between the handling of exchange messages and of toll messages. At present more than 90 per cent of the toll messages are completed while the subscriber remains at the telephone with speeds of completion only slightly slower than those of exchange messages. Transmission standards, while naturally somewhat better for the shorter distances involved in exchange messages, are, nevertheless, rapidly becoming very comparable. The present view of trends for the future is for continuation of this process, perhaps even to the use of similar types of machine equipment at central offices for switching the various classes of messages.

Additional Transcontinental Lines

In order to justify the reference to transcontinental telephony in the title of this discourse, I must return to it from time to time. I do so again at this point to mention that the original line with 3 circuits has now become four routes with 178 circuits. It may have been surmised from the discussion of the toll-switching plan that the number of coast-to-coast circuits must have mounted steadily and that they probably were directed over divers routes. This, precisely, is the situation. Following the historical sequence, second in order of time was a line running west from Dallas, Tex. (1923) and terminating in Los Angeles, Calif. This carries 51 circuits, 27 voice frequency and 24 carrier. Next there followed the so-called northern transcontinental line which runs west from Minneapolis, Minn., and terminates at Seattle, Wash., and which has 6 voice-frequency and 9 carrier-frequency circuits. Finally, there was completed about three years ago a fourth route which runs west through Oklahoma City, Okla., and, passing through Albuquerque, N. M., terminates in Los Angeles. It carries 4 voice-frequency and 52 carrier-frequency circuits. As may be seen, therefore, carrier systems predominate today in supplying facilities for the longest distances. I might add that whereas earlier carrier systems developed some 20 years ago were designed to provide 3 and 4 carrier circuits per pair of wires, the latest systems to be introduced, for both open wire and cable, are 12-channel affairs, while the coaxial cable now undergoing installation for commercial service will provide hundreds of telephone circuits on a single pair of conductors. Of course, these systems are and will be increasingly used on routes other than transcontinental. At present we have a total of about 600,000 miles of carrier circuits, and so far as the telephone user is concerned, and even so far as our own traffic people are concerned, there is no distinguishable difference between a voice-frequency and a carrier circuit.

Earlier I mentioned the electric wave filter invented by Campbell. It is, of course, in connection with carrier systems that the filter finds its most important application in telephony. It provides a most elegant scheme for separating at the point of reception the various messages that a carrier system handles simultaneously. As stated before, it was an outgrowth of the mathematically deduced characteristics of the loaded line. Thus, we stumble upon another interesting relationship. What we put out at one door comes around through another, for while we have dispensed quite generally with loading coils on long lines in order to adapt them to carrier operation, carrier itself would not be feasible were it not for the wave filter which grew out of the loaded line.

Overseas Radio Extensions

From carrier systems it is natural to digress for a moment to other high-frequency facilities. Chief among these are the radiotelephone channels, some overseas and some for ship-to-shore and harbor operation. The topic of radiotelephony is pertinent to the present discussion for quite another reason, however. It was less than a year after the first transcontinental line was opened in 1915 that we succeeded in transmitting speech by radio across the Atlantic Ocean. Words emanating from the Arlington antenna near Washington, D. C., were received at the Eiffel Tower in Paris, use of both structures having been granted for the purposes of the experiment. The vacuum tube, which brought success to the transcontinental program, began early to show its versatility. However, transatlantic equipment of 1915 was crude in the extreme compared with what proved necessary to offer a commercial overseas service. Although a one-way demonstration from New York to London was given in 1923, it was not until 1927 that the British Post Office, which operates the telephone system in Great Britain, countered with a transmitter to send from east to west. Since that time, overseas channels have bobbed up with surprising rapidity all around the earth so that today some 97 per cent of all the telephones in the world can be connected, one to another. From the United States we can telephone to 74 other nations—or can when peace-time conditions prevail.

I must now undertake to conclude this discussion of what grew out of one particular kernel, if you will allow me to refer to a circuit some 3,000 miles in length as a kernel. Perhaps it might better be compared with one of those long chain molecules which the chemists are employing these days with surprising results. Time forbids more than a mere mention of numerous other essential devices which are playing their part in this broad subject of present-day telephone transmission. Such things as phase correctors, automatic gain control of repeaters, volume compressors and expanders, and echo suppressors, ought really to receive more comment, to say nothing of various refinements in operating techniques which have been of great importance. However, I trust that I have succeeded in giving at least a glimpse of how some of the chapters of this technological romance have unfolded.

Thirty years ago the problems of long-distance telephony, and particularly the problems of transcontinental telephony, were very concrete transmission problems. Because the greater obviously included all the lesser, it was taken for granted that a satisfactory solution of transcontinental telephony would have far reaching effect on all long-distance telephony. For the most part we thought of the effect in terms of transmission rather than such things as speed of service or toll-switching plans.

It would be easy to claim too much for the descendants of the physical things that were first utilized commercially in the transcontinental circuits of 1914–15. At the same time, it is largely because of these descendants developed to do a multitude of things that we have present-day national and international telephone service; that the distant party is obtained while the calling party is still at the telephone; that we have a toll-switching plan and can contemplate a better one; and that we can talk about circuits which girdle the globe or operating methods which tend to wipe out existing differences between local and long-distance service.

None of us who were in the game from the start, 30 years ago, were bold enough to envisage what is commonplace today. But each success inspired new effort both in laboratory and field, and by a process of probing into Nature, inductively in the laboratory and deductively by means of mathematics, and with constant study of operating problems, we have, I believe, made creditable progress. I want to emphasize the fact that close co-operation was necessary every foot of the way. In bringing the fruits of science to the service of a vast public in a manner such as the telephone accomplishes, there has been no room for the dictatorial method, except of course as Nature does the dictating. We must try at all times to plead our case intelligently before Nature, and sympathetically before the public. As a matter of fact, the public and its reactions are as much a part of Nature as the electrons that carry our messages, and transgression of its laws of reaction would have been about as inimical to success as would a failure to understand the laws of electromagnetism.

In its journey during the last quarter of a century, telephony has crossed several thresholds, but, even so, the journey may be in its early stages. From the vantage point of the laboratory we see many promises of progress ahead and others quite unforeseen are certain to turn up. I feel, however, that there is something about this casual notion that, like the brook, science and its applications run on forever, which we should not accept too uncritically.

Illumination Notes

Midget Photoflash Lamp. Ten years ago the photoflash lamp appeared, freeing night photography from the nuisance of smoke and the danger of burns that accompanied the use of magnesium flashlight powder. The lamps were the size of ordinary lamp bulbs, so that one filled a coat pocket and a dozen made a fairly large package. Now the "mighty midget" photoflash lamp has been brought out by the Mazda lamp manufacturers. It is smaller than a golf ball, so that a dozen may be carried in one pocket with ease, but it gives a peak flash of nearly a million lumens. It is made with a bayonet base, so it requires an adapter for use in standard sockets.

Contributed for the AIEE committee on production and application of light by L. A. Hawkins (A'03, M'13) executive engineer, research laboratory, General Electric Company, Schenectady, N. Y.

Progress in Power Generation—1933–39

This report of the AIEE committee on power generation* reviews practices and developments in this field since 1933, when the last progress report of the committee was published. It divides itself naturally into three main parts discussing steam, electric, and hydroelectric plant practice. A comprehensive bibliography is appended.

DURING the past six years the most important advances in power generation have been made in the use of 3,600-rpm high-temperature high-pressure steam-turbine hydrogen-cooled generators of large size. Boiler design and construction has been changed to insure sufficient circulation, and welding has taken an increasingly important part in almost every part of the plant equipment, both mechanical and electrical. The period has marked the installation of many superposed units whereby the capacity of existing plants has been increased and the thermal efficiency materially improved. Because these stations are largely located near load centers from which distribution districts are served, there has been much rebuilding and extension of switching facilities of improved design and layout. These changes have greatly lessened the possibility of service interruptions from fire or other causes. Hydraulic power projects have been largely in the hands of Federal agencies. The output of existing hydroelectric plants in many parts of the country has been severely reduced owing to lack of rainfall during the past year.

With the European war there arises the prospect of extra demands on the electric-power systems for manufacturing purposes. For present requirements ample generating capacity is available with a sufficient margin to meet a considerable increase in load. To maintain this margin for growth much new capacity is under construction. In addition, since the beginning of the war about 400,000 kw of steam turbine-generator capacity has been ordered. It is interesting to note that this further expansion is being carried out along the same lines as would normally be followed. It is simply a quickening of the pace of construction, all consistent with earlier prepared plans for plant extension.

Equally careful to the steps being taken to insure an adequate power supply must be the attention given to the physical safety of the plants in operation and under construction. This means special guarding and other precautionary measures.

Steam-Plant Practice

Since 1933, and as predicted then, practically no new large generating stations have been built and very few small ones. Activity has been confined to rehabilitation, principally in the form of superposition of existing capacity. There have also been a number of condensing additions to existing stations.

Development of metals has resulted in an increase of operating steam temperatures from a maximum of 850 degrees Fahrenheit then to 950 degrees. This increase has made possible the superposition of nominal 1,200-pound units on existing 200-pound capacity without the complication of reheat, and consequently this type of installation has been more attractive than heretofore. Also, curtailed economic activity and limited load growth made the relatively small capacities obtainable by this method more in line with requirements. As a result 1,200-pound pressure has become quite common. There has been little tendency to go further in pressure as with present steam temperature limitations reheat would be required. One utility installation, however, is proceeding with a 2,500-pound plant; also, an industrial installation is in operation at this pressure. There has been no commercial installation of any appreciable size for higher pressure than 2,500 pounds, as this is now considered the limit for natural boiler circulation, and forced circulation is as yet untried in the United States for large units.

Boilers

Boiler sizes have not increased since the last report of this committee, remaining at a maximum of about 1,000,000 pounds per hour. Recent large installations have indicated that the sectional-header boiler is not as desirable for high pressure as other types because of improper distribution of water circulation between individual tubes in the vertical headers. Practically all new high-pressure boilers now under construction are of a type in which the boiler surface proper is either eliminated entirely or disposed nearly vertically with individual tubes entering the steam drum. Welded steel drums are almost universal. All high-temperature installations employ superheat control, consisting of some form of gas by-passing part or all of the superheater surface. Higher pressures have increased the problem of obtaining pure steam. Recent developments indicate that washing is unnecessary, providing either a suitable scrubber or baffling is installed and precautions are taken to hold proper boiler water level in the steam drum. One very satisfactory method of accomplishing this, which has been developed recently, is by means of cyclone separators installed on the outlet of the circulating tubes entering the steam drum.

The trend toward pulverized coal for large boiler units has persisted. Direct-fired systems have been improved to a point where it is difficult to justify the additional expense of a storage system. This has stopped development of large pulverizer units, about 25 tons per hour

* Personnel of 1938–39 AIEE Committee on Power Generation: R. C. M. Stahl, *chairman;* H. C. Albrecht, F. A. Annett, G. M. Armbrust, W. L. Cisler, C. A. Corney, H. M. Cushing, J. H. Foote, R. L. Frisby, W. D. Hardaway, N. B. Hinson, J. W. Lingary, S. J. Lisberger, C. E. Magnusson, A. C. Monteith, E. P. Pearson, G. G. Post, C. R. Reid, A. E. Silver, Philip Sporn, Robert Treat, Sidney Withington, and E. D. Wood.

For all numbered references see list at end of report.

being the maximum required. Combustion rates in furnaces remain about the same. Slag-bottom furnaces have been on the increase, and on recent units continuous slag tap has displaced the intermittent type. There has been a tendency toward bare water-cooled walls, eliminating blocks and studs.

Zoned air control for stokers has not advanced as expected. Principal development on underfeed stokers has been an improved tuyère which restricts air flow through the fuel bed at points of low resistance. Present experiments, which look promising, are high-velocity overfire air and auxiliary oil burners over the fuel bed.

Turbine Generators

There have been no further installations of very large turbine-generator units, the largest now under construction being a 100,000-kw cross-compound 3,600-rpm unit for the Burlington (N. J.) generating station of the Public Service Electric and Gas Company. Where high pressure and high temperature have been employed, there has been a preference for 3,600-rpm turbines because of smaller parts and less tendency for distortion. First-stage blading for the larger machines at this speed has presented a problem in design which has not been entirely solved. Apparently it is a matter of providing sufficient mechanical strength in the restricted space available, along with disposition of parts in a manner that will avoid resonant vibration.

Large-capacity generators for 3,600 rpm made necessary considerable advance in design. The largest generator in operation at this speed in 1933 had a capacity of 18,000 kw, whereas there are now in service a 60,000-kw and several 50,000-kw machines. Increase in capacity has been made possible by the use of high-tensile-strength steels for the fields, hydrogen cooling, and improvements in detail design. Operation of these larger machines has been in the main satisfactory, although there has been some trouble with double-frequency vibration.

There has been very little development of condensers, probably because of the relatively few condensing units installed.

Welding of piping has been carried out to a greater degree than before, and it is now common practice to weld valves into the line. Welded bonnets for high-temperature valves seem to be in the offing.

Ljungstrom Turbogenerators

Considerable interest has been aroused in engineering circles by the installation in the Southwick Power Station, Brighton, England, of two 37,500-kw Ljungstrom turbogenerators (see figure 2). These are the largest of their kind in England, although sets developing 50,000 kw are in service in the Vastreas station, Sweden. It is claimed that these latter turbines have shown conclusively that the difficulties once associated with their construction have been completely overcome. It is also confidently predicted that these double-rotation turbines in a single cylinder can be built up to a capacity of 100,000 kw. One of the major advantages claimed for this design is that the turbine may be started without preliminary warming up. Test data on the Brighton machine operating at a pressure of 650 pounds per square inch and a temperature of 850 degrees Fahrenheit with 29-inch vacuum indicate a heat rate of 9,759 Btu per kilowatt-hour.[91] With the present development of this type of turbine they are now adaptable to feed-heating cycles.

Gas Turbines

Cognizance must be taken of the more recent developments in gas turbines. One of the accelerating factors in this development is the fact that they are being used to provide bombproof stand-by plants, particularly in the fortified areas of Europe. A notable installation is in the city of Neuchatel, Switzerland. These turbines require no cooling water and no auxiliaries when in operation. Over-all thermal efficiencies have attained 23 per cent with well over 20 per cent for the normal operating range.

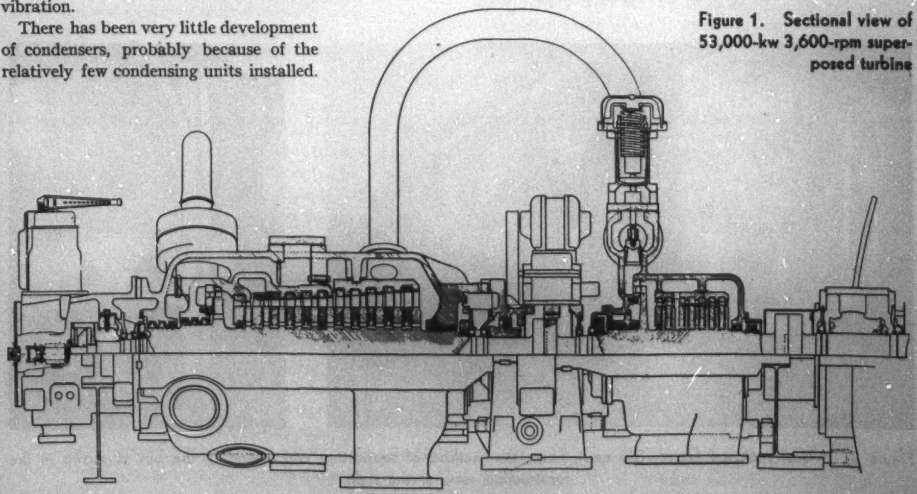

Figure 1. Sectional view of 53,000-kw 3,600-rpm superposed turbine

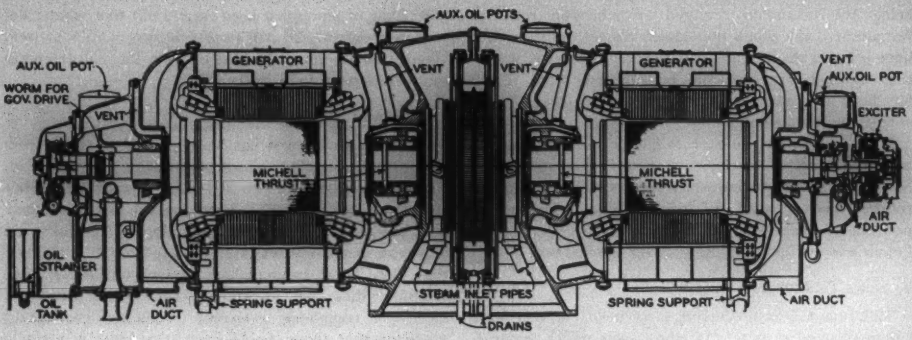

Figure 2. Sectional elevation of Ljungstrom turbine and generators

So far, gas turbines have attained capacities of 4,000 kw.[93]

Mercury Cycle

There have been no additional mercury boiler installations for power generation, although the Sun Oil Company has installed another boiler used in oil distillation process. Considerable trouble developed with the Kearny, N. J., and Schenectady, N. Y., boilers described in the 1933 report of this committee. The Kearny boiler is now being completely replaced. The design of the new boiler is similar to water-boiler design in that there is only one drum. "Porcupine" tubes with internal cores and close clearances have been eliminated. The convection surface is new in principle in that instead of being completely filled with a liquid it carries a mixture of liquid and vapor, resulting in a marked reduction in the amount of mercury required per unit of heating surface. As a result of the elimination of tube cores, however, the total amount of mercury in the boiler is somewhat increased. In the redesign the water-wall furnace has been eliminated, resulting in a marked improvement in over-all efficiency. New materials now available and more suitable for the operating conditions involved are being utilized in the various parts of the heating surface. Operating practice, and particularly chemical treatment of mercury in the boiler, has advanced considerably. The mercury turbine generators have been very satisfactory, and the only recent change in design involves improvement of the turbine glands to reduce air leakage to a minimum.

Electrical-Plant Practice

Generating-Station Switching

Since 1933 few new steam generating stations have been built requiring low-voltage power distribution, with the accompanying bus-layout problems. Large new stations have been mainly of the hydroelectric type, far removed

Figure 3. Metal-enclosed feeder bus equipment; the method of supporting and insulating the bus is shown in the construction view at the right

from local load, with generators connected directly to transformer banks or through a minimum of low-voltage switching equipment with outdoor high-voltage switch yards for the connection to the transmission lines, such as the Boulder Dam development.[109]

The generator-voltage switching facilities of several stations have been reconstructed and modernized due in some instances to the addition of generating capacity or extensive interconnecting of systems, and in others to interruptions caused by fires in the older types of switch houses.

One of the first large stations to be modernized was the Connors Creek station of the Detroit (Mich.) Edison Company.[98] In this instance a new switch house, separated from the existing station building was erected to house the modern bus and apparatus.

In the last few years this topic has become of such interest that at the AIEE winter convention in January 1939 the committee on power generation held a session on the rehabilitation of the various stations of the Consolidated Edison Company of New York,[117] the Essex generating station of Public Service Electric and Gas Company of New Jersey[119] and the L Street station of the Boston Edison Company,[116] together with a paper on the general topic.[118] The papers presented at this meeting describe in detail the problems that were present at the various locations, the aim of reconstruction programs, and the methods used by the various designers to obtain the results desired. The authors in agreeing on certain principles show clearly the present trend of switch house construction:

1. Complete relay protection.
2. Improved arrangement of equipment.
3. Limitation of capacity connected to one bus section, so that a fault will not remove too great a proportion of the station capacity.
4. Better physical segregation of bus sections and oil circuit breakers, by means of smoke and fire barriers, coupled with forced ventilation.
5. Reduction of oil content of breakers.
6. Use of improved fire-fighting equipment.
7. Improvement as to control, segregation, and grounding.

As the length and extent of several recent interruptions were in part due to smoke and soot deposits on insulators and busses of portions of the station not directly involved in the fault, great pains have been taken in these rebuilding programs to segregate indoor sections physically. Barriers, without direct doors or other openings between sections, are desirable if the conditions permit. Access to sections is obtained from corridors or rooms free of electrical apparatus, which also may provide expansion space for the dissipation of pressures generated by explosions. With large-capacity ventilating systems to clear the faulted section of fumes, and with adequate fire-fighting equipment present, these modernized switch houses have a strong second line of defense if, in spite of improved protective schemes, an explosion or fire occurs. Recent tests demonstrating the capabilities of fire-fighting equipment and aiding in the training of operating forces have permitted more assurance in their effectiveness. Equipment of both the carbon-dioxide type and of the fine-water-spray or mist type, in both portable and permanently piped systems, has been used.

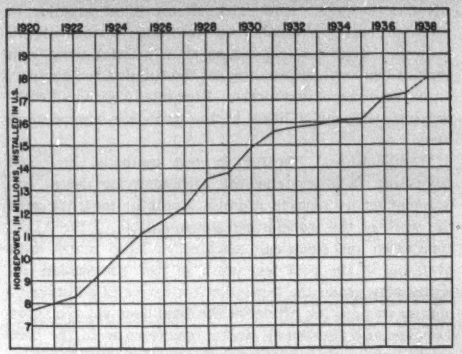

Figure 4. Growth of water-wheel installations in all classes of hydraulic plants in the United States

One of the most interesting recent developments is the nonmagnetic-steel-tube-enclosed gastight bus of the Consolidated Edison Company of New York,[117] which allows phase segregation and high carrying capacity in limited space. A number of installations of the more conventional metal-enclosed bus structures with metal breaker cubicles have been made, and in many such instances fault bus protection has been adopted, although differential protection is in use in the majority of cases.

Electrical Equipment

There has been a marked improvement in apparatus and equipment since the 1933 report. Extensive tests on oil circuit breakers with the modern arc-extinguishing devices have produced a breaker both electrically and mechanically more reliable than was heretofore available.

Opening times of eight cycles are now standard, and breaker speeds of five and three cycles may be obtained when necessary.

Many old oil circuit breakers have been equipped with the new arc-extinguishing devices and higher-speed mechanisms to gain in interrupting capacity and reduce the time to the present AIEE standard.

The tendency to reduce the oil content of breakers has caused a general interest and demand for oilless breakers, which has resulted in an increased use of available designs and new developments by the manufacturers. Breakers of the air De-ion type are in service with up to 750,000-kva interrupting capacity; breakers of the hydro-blast type are in service rated at 500,000-kva interrupting capacity with orders placed for capacities up to 1,500,000 kva; and breakers using compressed air as an arc-extinguishing medium are on order with interrupting capacity of 500,000 kva and are designed with ratings up to 1,500,000 kva.

Disconnecting switches have been developed for large capacities, mainly of the high-pressure type, using button or line contacts, or positive clamping action, all with

silvered contacts; tests have shown them superior to those previously available for continued service at full loadings. High-capacity busses show a trend away from the flat-bar configuration toward the tubular, rectangular, or double-channel iron forms. Busses both with and without insulation in addition to the porcelain supports are used.

Manufacturers' research in test methods, increased laboratory facilities, and the accompanying design improvements as regards impulse strength, together with the work of the transformer subcommittee of the AIEE committee on electrical machinery, have made data available in the past few years so that the station designer may grade the insulation for surges in addition to normal frequencies, although the time is as yet too short to cause any agreement among operators as to the best co-ordination of insulation between line, transformers, breakers, and bus.

Transmission of Bulk Power

Interconnection of large systems for bulk power interchange has continued which, with the hydroelectric-station development, has resulted in numerous 220-kv lines, the highest commercial voltage in the country being the 287 kv of the lines from Boulder Dam.[106] This interconnection of systems has caused further stability problems, which, together with the desire to reduce the damage caused by faults and lighten the effect on customers' services, has resulted in the development of high-speed relaying, both of the distance and balanced type, and the carrier-current and pilot-wire type; these types of relaying are being applied to transmission of all voltages. Relay times of one cycle or less are available, which, combined with five- or three-cycle breakers, give rapid clearing of faults where such extreme speed is necessary. To aid in permitting systems to ride through overhead line disturbances, the use of the Petersen coil, rapid reclosing of breakers, and discharge tubes is increasing.

The use of high-voltage cable for transmitting large blocks of power has increased, approximately 79 miles having been installed for 66 kv and above since 1933.

Station Auxiliaries

The majority of the steam additions to existing plants use electrical auxiliaries. Higher-pressure boilers have increased the demand for higher-speed boiler-feed pumps, and the trend is toward constant-speed or multi-speed motors for both this service and the forced- and induced-draft fans. Constant-speed squirrel-cage induction motors have been built as large as 2,000 horsepower for feed-water pumps and up to 700 horsepower in the wound-rotor type. Three-phase supply, 2,400 volts, is quite standard for this type of auxiliary, and the factory-built metal-enclosed bus structure is in general use, the lift type of breaker being popular. Air circuit breakers of the 5,000-volt 100,000-kva class are now available from several manufacturers for auxiliary station service, and as many consider it just as desirable to reduce oil contents of boiler rooms as of switch houses, the air breakers show increasing use. Noninflammable liquid, first applied to distribution transformers, is now used in power transformers and is particularly adaptable for auxiliary service in station locations where oil would be a hazard. More study is being made to ensure the continuity of auxiliary service, of obtaining separate sources of supply, and complete protection of auxiliary buses. The increasing use of pulverized fuel, with its intricate and delicate starting procedure, has introduced additional problems in

Table I. Government Hydroelectric Projects

Government Agency	Project	State	Ultimate Capacity (Horsepower)	Initial Capacity (Horsepower)	Installed Capacity (Horsepower)	Capacity on Order (Horsepower)
U. S. Bureau of Reclamation	Grand Coulee	Wash.	2,742,000	478,000		478,000
U. S. Engineer Corps	Bonneville	Wash.	665,000	137,000	137,000	148,000
U. S. Bureau of Reclamation	Shasta Dam	Calif.	515,000	412,000		412,000
Imperial Irrigation District	Drop 4	Calif.	26,600	13,300		13,300
U. S. Bureau of Reclamation	Boulder Dam	Nev. & Ariz.	1,835,000	515,000	752,000	230,000
U. S. Bureau of Reclamation	Elephant Butte	N. M.	34,500	34,500		34,500
U. S. Bureau of Reclamation	Casper-Alcova	Wyo.	45,000	45,000		45,000
U. S. Bureau of Reclamation	Green Mountain	Colo.	30,000	30,000		30,000
U. S. Bureau of Reclamation	Colo.-Big Thompson	Colo.	135,000	*		
U. S. Engineer Corps	Fort Peck	Mont.	100,000	*		
Platte Valley Public Power & Irrigation	Dist. Platte Valley	Nebr.	35,000	35,000	35,000	
Loup River Public Power District	Loup River	Nebr.	65,000	65,000	65,000	
Central Neb. Public Power & Irrigation District	Tri-County	Nebr.	54,000	26,000		80,000
Grand River Dam Authority	Pensacola Dam	Okla.	100,000	80,000		80,000
Lower Colo. River Authority	Buchanan Dam	Texas	51,900	34,600	34,600	
Lower Colo. River Authority	Tom Miller Dam	Texas	20,000	20,000		20,000
Lower Colo. River Authority	Inks Dam	Texas	16,000	16,000	16,000	
Tenn. Valley Authority	Norris	Tenn.	132,000	132,000	132,000	
Tenn. Valley Authority	Pickwick	Tenn.	330,000	110,000	110,000	
Tenn. Valley Authority	Wilson	Ala.	620,000	260,000	260,000	
Tenn. Valley Authority	Wheeler	Ala.	360,000	90,000	90,000	90,000
Tenn. Valley Authority	Guntersville	Ala.	136,000	102,000		102,000
Tenn. Valley Authority	Chickamauga	Tenn.	144,000	108,000		108,000
Tenn. Valley Authority	Hiawassee	N. C.	160,000	80,000		80,000
Tenn. Valley Authority	Gilbertsville	Ky.	350,000	*		
Greenwood County Power Authority	Buzzards Roost	S. C.	30,000	22,200		22,200
South Carolina Public Service Authority	Santee-Cooper	S. C.	213,000	*		213,000

* Work started, but no information on initial horsepower available.

continuity of service during system disturbances, and undoubtedly more thought will be given to either ensuring the maintenance of auxiliary-bus voltage or automatic starting of the pulverized-fuel equipment.

Hydroelectric-Plant Practice

Annual water-power figures are beginning to look like those for 1928 and 1929, predepression years. During 1938 about 750,000 horsepower of new capacity went into service, bringing the total capacity of water wheels to around 18,000,000 horsepower for the United States, as shown by figure 4. At the present time in the United States over 2,000,000 horsepower of water-wheel capacity is under construction and work has been started on other projects representing an ultimate installed capacity of 750,000 horsepower for which the power units have not yet been ordered.

A large part of this capacity is in plants being built by governmental agencies. There are, however, many projects being developed by public-utility and industrial companies, particularly in the northeastern and mid-western sections of the country. In 1937 and 1938 work was started or completed on over 60 of these projects, representing an initial capacity of 500,000 horsepower.

Notable among public-utility projects are the four 26,000-horsepower units for 110-foot head in the Claytor development of the Appalachian Electric Power Company on the New River, Virginia; the 77,000-horsepower unit for 188-foot head installed in the Kerr power house of the Rocky Mountain Power Company on the Flathead River in Montana; the 14,700-horsepower and the 8,400-horsepower units for 91-foot head in the Grandfathers Falls power house of the Wisconsin Public Service Corporation; and the 10,950-horsepower unit for 45-foot head being installed in the Solon development of the Central Maine Power Company. Several other projects have been put into operation or under construction by public-utility companies in Maine, Vermont, New York, Virginia, Wisconsin, and other states.

In point of installed capacity, water-power projects being built by governmental agencies exceed all others. These, including those that have been built and on which work has been started, represent an ultimate capacity of over 9,000,000 horsepower, or one-half of the total installed in the United States. Nearly 3,500,000 horsepower of this is for Bonneville and Grand Coulee plants on the Columbia River, 526,000 horsepower in California, and 1,835,000 horsepower at Boulder Dam (see table I).

These projects represent about two-thirds of the total ultimate capacity. Of the remaining third over 2,000,000 horsepower is represented by projects of the Tennessee Valley Authority on the Tennessee River, leaving only about 1,000,000 horsepower in other parts of the country. TVA projects include Wilson Dam plant with space for 610,000 horsepower, built before that organization was created by Congress.

By June 1939, only 1,631,500 horsepower had been installed in Government financed projects since 1932, and this includes 260,000 horsepower in Wilson Dam plant.

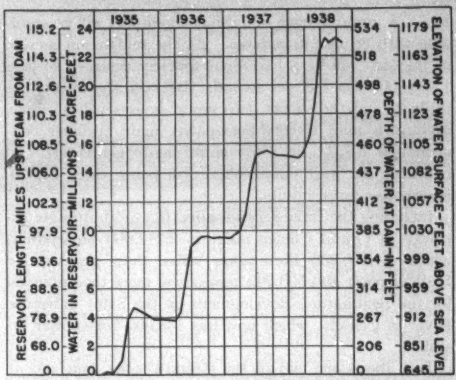

Figure 5. Rate at which Boulder Dam reservoir has filled since closing of the by-pass tunnels in 1935

For these plants there are on order machines having an aggregate capacity of 2,000,000 horsepower of which 1,250,000 horsepower is for Grand Coulee, Bonneville, Shasta, and Boulder plants, in sections normally supplied by water power.

Outside of Bonneville development, all the large governmental water-power developments in the Pacific Coast area are essentially water-supply and river-regulation projects from which large amounts of power can be generated, much of which will be required to pump water for municipal supply and irrigation. Grand Coulee is the largest of these and in fact is the largest in the world on which reliable data are available. It includes a straight concrete gravity-type dam 4,500 feet long, 553 feet high, and 500 feet thick at the base.

This dam will back the water up the river 150 miles to the Canadian border to form a reservoir with 9,645,000 acre-feet maximum storage and a maximum head of 360

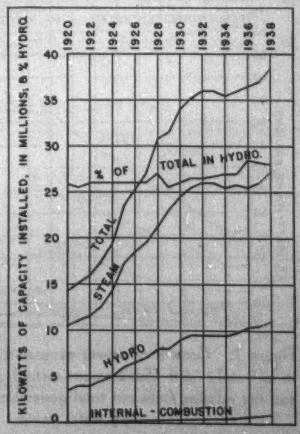

Figure 6. Growth of installed generating capacity in both privately and Government-owned public-utility plants of all classes in the United States

feet. A useful storage of 5,200,000 acre-feet will be available with 80 feet drawdown. At the midstream section of the dam will be a 1,650-foot spillway designed to pass 1,000,000 cubic feet per second. Between the ends of the spillway and the shores, two power houses will be built, each with nine 150,000-horsepower main turbines connected to 108,000-kw unity-power-factor generators. In addition, the west power plant will house three 14,000-horsepower service units.

Including the three service units, the total ultimate capacity of Grand Coulee plant is 2,742,000 horsepower, which is 900,000 horsepower more than planned for Boulder plant and 500,000 horsepower more than planned for the Beauharnois development on the Saint Lawrence River in Canada, which now has 483,000 horsepower installed.

Just above one end of the Grand Coulee dam and at right angles with it will be a pumping plant containing 12 vertical 65,000-horsepower synchronous-motor-driven pumps. Each pump will have a capacity of 1,000,000,000 gallons per day when pumping against a 295-foot head. These pumps will lift water from the main reservoir into a secondary reservoir formed by a dam across the lower end of the Grand Coulee, from where the water will flow to irrigate 1,200,000 acres of land. Six generators in the power house adjacent to the pumping plant will supply power to the pump motors. Three main generating units and two service units are now on order and are scheduled for initial operation in 1941.

Part of the power from the Shasta development now under construction on the Sacramento River in California will be used for pumping irrigation water. This project will have an ultimate capacity of 500,000 horsepower, of which four 103,000-horsepower units to operate under a 450-foot head are on order.

So much has been written about Boulder Canyon project that one hesitates to say more. But this project has so many interesting features that a report on water-power development would not be complete without calling attention to some of them. Construction work was started in 1931 and operation began in 1936. The project has four major purposes; namely, flood control, supply water for irrigation and municipal use, and power generation.

In the power house, which is designed for an ultimate capacity 1,835,000 horsepower, 752,000 horsepower has been installed and two 115,000-horsepower units are on order. These will give this plant the largest installed capacity of any hydroelectric project in the world, and the only steam plant to exceed its present capacity is the Hudson Avenue station, Brooklyn, N. Y., which has 770,000 kw installed. Eventually, 400,000 horsepower of pumping load on the Metropolitan Water District aqueduct, running from the Colorado River to Los Angeles, Calif., will be supplied by Boulder Dam. Initial installation of this aqueduct goes into operation this year.

Figure 8. This 42,500-horsepower Kaplan-type propeller runner has its blade surfaces machined and polished all over

As figure 5 shows, Boulder Dam, which is 730 feet high and forms a reservoir of 30,500,000 acre-feet capacity, has prevented several floods that would have been disastrous on the lower river, and has also prevented irrigation-water shortages. The sharp rise in the curve each year during May and June shows how severe the floods are. Last year during this period 6,000,000 acre-feet of water was stored. This is equivalent to a continuous flow of 55,000 cubic feet per second for two months, in addition to the water permitted to flow down the river. If average water supply is obtained in the river this year the reservoir should be filled to capacity.

These water-power developments by governmental agencies naturally raise the much discussed question of hydraulic versus steam plants and what effect these new hydraulic plants are having on the relation of hydroelectric and steam-electric installed capacity and generation. In spite of all the activity in water-power development by governmental agencies, the growth in hydroelectric generating capacity was more rapid before 1932 than since then, when the Government seriously entered the field, as is evident from figure 4.

For example, for the seven years from 1925 to 1931, inclusive, installed water-power capacity increased nearly

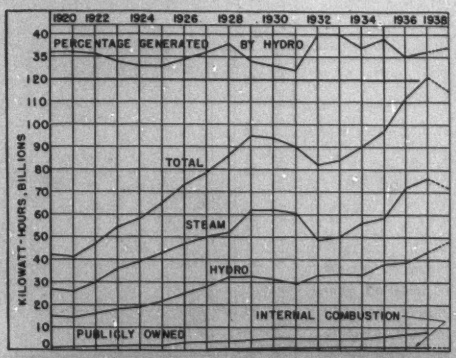

Figure 7. Growth of power generated in the United States in privately and Government-owned public-utility plants, and the relation between total generation and that produced by water power

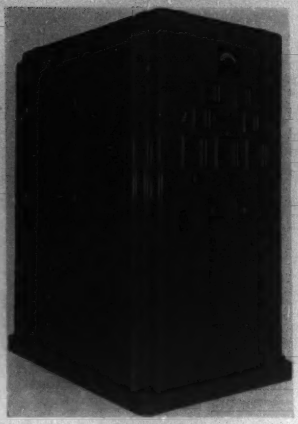

Figure 9. Modern type hydraulic-turbine-governing unit combines all parts of the governing system into a single cabinet with the exception of the servo-motors and generator for driving the actuator

5,500,000 horsepower, where from 1932 to 1938, inclusive, only 2,250,000 horsepower has been installed. Of course it must be admitted that the depressed condition of business has been a factor in the latter. But, if we compare only the three years from 1936 to 1938, inclusive, with the nine years from 1923 to 1931, inclusive, the latter shows a considerably steeper rise than the former. An even more important factor than the depression in slowing up water-power growth is that efficiency of steam plants has increased and their cost of construction decreased to where in many localities they now seriously challenge water-power developments on an economic basis.

An outstanding example of steam-plant construction in a water-power region is the new 160,000-kw plant of the Buffalo, Niagara and Eastern Power Corporation, being installed at Oswego, N. Y., in a region largely served by water power. Installation of this steam plant was not dictated by any shortage of water-power sites, for the company controls several within easy reach of where it is being built. When all factors were considered, economic and otherwise, the steam plant proved to be the most desirable. The city of Eugene, Ore., which operates its own power system and is only 160 miles away from the Federal Government's Bonneville hydroelectric plant, announced plans for a new peak-load steam or Diesel plant during the latter part of 1938. In 1937 the Tennessee Electric Power Company won the right from the State Public Service Commission to install a steam plant at Nashville, Tenn., by proving that this type of plant could supply power to its system more economically than it could be obtained from the Government-subsidized TVA hydroelectric system. Since then this plant has been sold to TVA.

Figure 6 shows the total generating capacity installed in all types of power plants operated by both privately and Government-owned utilities. Also the division of this capacity between steam, hydraulic, and internal-combustion-engine stations. A curve has also been added to show the relation that installed hydroelectric capacity bears to the total. This relation has remained remarkably constant since 1920. In this period installed hydroelectric capacity has increased only 2.1 per cent, or from 25.9 to 28 per cent of the total installed in all classes of plants.

Figure 7 shows power generated by the private and public agencies represented by figure 6. An interesting feature about these curves is that the per cent of total power generated by water power was practically the same (36 per cent) for 1937 as for 1920. Because of the total power load falling off sharply in 1938, and an abundant rainfall in practically all parts of the country, the per cent of water power showed an increase to about 37.5 per cent. These two factors, load growth or loss and rainfall, have a marked influence, and account for most of the peaks and valleys in the water-power curve. From the foregoing it is evident that as yet the relation between fuel-burning and hydraulic plants continues on a practically even keel. The curves in figures 4, 6, and 7 are plotted from data published by the Federal Power Commission, with the exception of 1938 for which figures published by *Electrical World* are used.

Even though Francis-type wheels have been built in unprecedented size and power during recent years, it is in the low-head field covered by propeller-type wheels where the greatest advancements have been made. This type of wheel, because of its high speed, has greatly reduced the cost of developing low-head projects. Al-

Table II. Large Propeller-Type Water Wheels Installed in the United States and Canada

Name of Plant	State or Province	No. of Units	Rating (Horsepower)	Effective Head (Feet)	Discharge (Cubic Feet per Second)	Type of Runner	Runner Diameter (Inches)	Speed (RPM)
Bonneville	Ore. & Wash.	2	66,000	66	12,000	Kaplan	280	75
Bonneville	Ore. & Wash.	2	74,000	66	14,400	Kaplan	280	75
Pickwick Landing	Tenn.	2	55,000	47	12,000	Kaplan	290	81
Wheeler	Ala.	2	45,000	48	9,000	Fixed blade	264	85.7
Safe Harbor	Pa.	6	42,500	55	8,000	Kaplan	220	109.1
Chickamauga	Tenn.	3	36,000	36	11,000	Kaplan		75
Guntersville	Ala.	3	34,000	36	10,000	Kaplan	265	69.2
Rock Island	Wash.	4	21,000	32	7,150	Manually adjusted blade	223	100
Louisville	Ky.	8	13,500	37	4,000	Fixed blade		100
Seven Sisters	Manitoba	3	37,500	66	5,700	Fixed blade	200	138.5
LaGabelle	Quebec	5	32,000	60	5,400	Fixed blade	195	120
Great Falls	Manitoba	6	28,000	56	5,000	Fixed blade	200	138.5
Chat Falls	Ontario & Quebec	8	28,000	53	5,300	Fixed blade	195	125
Island Falls	Saskatchewan	5	19,000	56	3,500	Fixed blade	145	163.6

Figure 10. Outdoor-type plant at the Wheeler Dam project of the Tennessee Valley Authority has two 45,000-horsepower units, with space for six more

though developed less than 25 years ago, these units have come into wide use in both North America and Europe, in both large and small size. Table II gives data on some of the largest units installed in the United States and Canada. This type of wheel has been developed in three forms: fixed blade; Kaplan, the blade angle of which is adjusted by the governor; and the type on which the blade angle is automatically adjusted by change of water flow through the runner as the load changes. With the fixed blade design, its efficiency curve falls off quite sharply either side of maximum, but by adjusting the blade angle, high efficiency can be obtained over a wide range of load and head.

This type wheel has permitted an increase in specific speed from a maximum of about 90 rpm for a Francis-type wheel to 150 rpm and higher. Because of their higher speed, cavitation assumes far greater importance than with slower-speed runners, particularly for the larger-size units. This problem is handled in two ways, first by locating the runner at an elevation below tailwater level that will limit cavitation to what is considered a safe amount. Then in the construction of the runner vanes, the areas where pitting because of cavitation is expected are chipped out and these filled in with stainless steel by welding, after which in some instances the blades are machined all over, ground, and polished, as in figure 8. Any pitted areas that occur in operation are also chipped out and welded in with stainless steel. Experience has shown that stainless steel will stand the action of cavitation better than any other.

Welding is assuming an ever-increasing importance, not only in the maintenance of water wheels but also in their construction. For example, in the Bonneville propeller-type units, practically all parts, with the exception of the runners and shafts, were constructed by welding.

Governors for hydroelectric units have been improved in their ability to control speed and have been radically changed in appearance. Where a few years ago the actuator and valves were in one place, the oil-pressure pumps in another, and the pressure tanks in still another, the modern governor has these parts along with all instruments and indicators combined in a single unit, as in figure 9. On the front of this cabinet actuator are a speed and frequency indicator, draft-tube vacuum gauge, penstock-pressure gauge, duplex gauge showing generator-brake-system air pressure and brake-cylinder pressure, duplex gauge showing auxiliary and main relay valve port positions, speed-droop indicator with knob directly below, gate-limit and gate-position indicator with gate-limit knob directly below, speed-adjustment indicator with control knob directly below, manual generator-brake-valve control knob, control knob for transferring from main to auxiliary valve control and vice versa, cabinet-light switch and pilot lamp, emergency shutdown switch and pilot lamp.

Outdoor-type hydroelectric plants, which 10 or 15 years ago were attracting considerable attention, have been adopted in only a few installations. Wheeler Dam plant of TVA, figure 10, is an outstanding example.

Bibliography

1. Buzzards Point, **R. B. Purdy.** *Power*, volume 78, June 1934, pages 318–19.

2. Buzzards Point Station, **W. J. Lank.** *Electrical World*, volume 102, December 30, 1933, pages 844–8.

3. Hudson Avenue Steam-Electric Central Station, Brooklyn, N. Y., **R. B. Purdy.** *Power*, volume 78, June 1934, pages 322–3.

4. Port Washington Power Plant Design, **G. G. Post.** Electrical Engineering (AIEE Transactions), volume 53, February 1934, pages 264–71.

5. South Amboy, **R. B. Purdy.** *Power*, volume 78, June 1934, page 320.

6. New Steam-Generating Unit Installed at Picway, **G. T. Shoemaker.** *Combustion*, volume 6, August 1934, page 7.

7. Advances in Power Apparatus, **F. D. Newbury.** *Electric Journal*, volume 32, January 1935, pages 6–9.

8. Design and Operation of Huntley Station No. 2, Buffalo, N. Y. (Bibliography), **H. Cushing.** Electrical Engineering (AIEE Transactions), volume 54, June 1935, pages 632–45.

9. Fort Wayne Completes New Power Plant. *Power Plant Engineering*, volume 39, November 1935, pages 604–05.

10. Mercury Vapor at Kearny. *Power*, volume 79, July 1935, pages 348–50.

11. New 165,000-Kw Addition at Richmond Station of Philadelphia Electric Co., **N. J. Walker, W. B. Morton, and H. Groothius.** *Power Plant Engineering*, volume 39, August 1935, pages 434–43.

12. 183,333-Kva Generator at Richmond Station, **C. M. Laffoon.** *Power Plant Engineering*, volume 39, September 1935, pages 508–10.

13. 165,000 Kw More at Richmond Station, **E. L. Hopping and F. P. Fairchild.** *Power*, volume 79, August 1935, pages 402–04.

14. 165,000-Kw Tandem Turbine at Richmond Station, **R. L. Reynolds.** *Power Plant Engineering*, volume 39, October 1935, pages 555–7.

15. Plant Modernization, **M. Penn.** Edison Electric Institute *Bulletin*, volume 3, July 1935, pages 277–80.

16. Port Washington Station Put Into Preliminary Operation by Milwaukee Electric Railway and Light Company. *Power Plant Engineering*, volume 39, November 1935, pages 636–7.

17. Port Washington Tips in High Pressure Plant of the Milwaukee Electric Railway and Light Company, **T. Wilson.** *Power*, volume 79, November 1935, pages 585–9.

18. Rehabilitation of the Connors Creek Plant (with cost data), **R. E. Greene.** Electrical Engineering (AIEE Transactions), volume 54, June 1935, pages 610–17.

19. Richmond Station Triples Generation Space Factor, **R. Wilbraham and R. Bailey.** *Electrical World*, volume 105, August 3, 31, 1935, pages 1884–8; 2112–15.

20. Additions to Steam Plant Capacity, **F. S. Clark.** *Electrical World*, volume 105, November 23, 1935, pages 2769–71.

21. Consolidated Edison System, **W. H. Lawrence.** *Electrical World*, volume 106, August 29, 1936, pages 2660–2.

22. Consumers Power Adding 10,000-Kw Superposed Unit. *Electrical World*, News Issue, volume 106, August 8, 1936, page 2436.

23. Load Area Detroit Plants, **P. W. Thompson.** *Electrical World*, volume 106, August 29, 1936, pages 2685–8.

24. Logan Steam Plant, a Landmark: Superposition of High Pressure Equipment and Hydrogen and Water-Cooled Generator, Appalachian Electric Power Company, **P. Sporn.** *Electrical World*, volume 106, April 11, 1936, pages 1017–19.

25. Modernized Connors Creek Station of the Detroit Edison Company, *General Electric Review*, volume 39, January 1936, pages 72–3.

26. New Cedar Rapids Top, **J. M. Drabelle and W. H. Proescholdt.** *Power*, volume 80, April 1936, page 203.

27. New 35,000-Kw Top Unit for West End, Cincinnati, **D. S. Brown.** *Power Plant Engineering*, volume 40, August 1936, pages 446–51.

28. New Top Plant for Rochester. *Power Plant Engineering*, volume 40, April 1936, pages 206–17.

29. Ohio Municipality Increases Generator Capacity, **Shelby.** *Power Plant Engineering*, volume 39, December 1935, pages 660–4.

30. 113,000 Square Feet in a Single Condenser Shell, Richmond Station of Philadelphia Electric Company, **D. W. R. Morgan.** *Power Plant Engineering*, volume 40, March 1936, pages 54–7.

31. Richmond Station of the Philadelphia Electric Company, **H. W. Cope.** *Electric Journal*, volume 33, January 1936, pages 18–19.

32. Rochester Superposed Plant, **I. G. McChesney and L. R. Scott.** *Electrical World*, volume 106, August 29, 1936, pages 2693–9.

33. St. Louis Expands First Unit of New Mound Street Top Plant. *Power Plant Engineering*, volume 40, November 1936, pages 618–22.

34. Springfield's (Ill.) New Lakeside Station, **S. J. Sibley and F. N. Glazier.** *Power Plant Engineering*, volume 40, July 1936, pages 386–92.

35. Superimposed Unit at Cedar Rapids, **W. H. Proescholdt.** *Electrical World*, volume 105, November 23, 1935, page 2811.

36. Superposition Turbine Going Into Fisk Street, **B. Schroeder.** *Electrical World*, volume 106, October 10, 1936, pages 3156–8.

37. Top Cuts Coal Rate 42 Per Cent: Use of High Pressure Turbine Exhausting Into Low Pressure System: Rochester Gas and Electric Corporation. *Power*, volume 80, April 1936, pages 197–200.

38. World's Largest Power Station: Hudson Avenue Station of Brooklyn Edison Company, **J. L. Landis and J. F. Fairman.** *Electrical World*, volume 106, August 29, 1936, pages 2665–8.

39. Modernizing the Connors Creek Plant, **S. Crocker.** *Combustion*, volume 7, 8 parts, November 1935–June 1936; November 1935, page 10; December 1935, page 10; January 1936, page 12; February 1936, page 12; March 1936, page 27; April 1936, page 27; May 1936, page 23; June 1936, page 27.

40. Superimposed High-Pressure Plant Extension of the Rochester Gas and Electric Corporation, **I. G. McChesney.** *Combustion*, volume 7, April 1936, page 16.

41. Delray No. 3: 3 New 75,000 Kw Units Will Increase Station Capacity. *Power Plant Engineering*, volume 41, May 1937, page 306.

42. Electrical Additions to Springdale, **H. A. P. Langstaff.** *Electric Journal*, volume 34, June 1937, pages 244–6.

43. Fisk's New Top Program Increases Capacity 30,000 Kw. *Power Plant Engineering*, volume 41, October 1937, pages 576–82.

44. Flue Gases Scrubbed Out in Boston Edison Plant. *Electrical World*, volume 108, August 28, 1937, page 681.

45. Hartford Reviews Plant Problem. *Electrical World*, volume 108, July 3, 1937, page 70.

46. Lynn Gas and Electric Company Adds Pulverized Fuel Boiler Unit. *Power Plant Engineering*, volume 41, June 1937, pages 328–34.

47. More Power to Cahokia, **E. H. Tenney and G. Williamson.** *Power Plant Engineering*, volume 41, April 1937, pages 206–09.

48. Some Engineering Contributions to Society: Improvement in Electrical Equipment, **R. C. Muir.** Edison Electric Institute *Bulletin*, volume 5, July 1937, pages 280–5.

49. Steel Point Installs 5,000-Kw Top. *Power Plant Engineering*, volume 41, July 1937, pages 390–7; 426–7.

50. Top for 12th Street, Richmond, Va., **R. S. Reed.** *Power*, volume 81, July 1937, pages 362–7.

51. 2,400 Pounds, a New Power Milestone; Twin Branch Plant of Indiana and Michigan Electric Company, **P. Sporn.** *Electrical World*, volume 108, October 9, 1937, pages 1203–08.

52. Welding at Waterside Station of the Consolidated Edison Company of N. Y., **W. S. Morrison and W. J. Angus.** *Power*, volume 81, September 1937, pages 480–3.

53. Superposition at Schuylkill Station of Philadelphia Electric Company, **E. L. Hopping.** *Combustion*, volume 8, June 1937, page 22.

54. "Topping" Extension to Omaha Steam Plant, **L. Elliott.** *Combustion*, volume 8, September 1936, page 20.

55. Windsor Steam Plant Modernization, **P. Sporn.** *Combustion*, volume 8, March 1937, page 20.

56. Mead River Steam Plant Addition to Go Into Operation. *Electrical World*, News Issue, volume 110, September 17, 1938, page 795.

57. Madison (Wis.) Plant Merges High Pressure With Low, **G. T. Shoemaker.** *Electrical World*, volume 110, July 2, 1938, pages 42–4.

58. Millers Ford Built to Run. *Power*, volume 82, June 1938, pages 300–03.

59. Modern Power Plants, **E. H. Krieg.** *Cornell Engineer*, volume 4, October 1938, pages 4–8.

60. Modern Utility Stations, Commonwealth and Southern System, **G. C. Daniels.** *Power Plant Engineering*, volume 42, March 1938, pages 164–9.

61. New Generator of Oklahoma Utility Marks Step in Expanding Service. *Electrical World*, News Issue, volume 110, September 3, 1938, page 649.

62. On the Line at Montville, 25,000-Kw Condensing Unit, **S. A. Tucker.** *Power*, volume 82, January 1938, pages 6–7.

63. Plant Design Modified by New Developments, Riverside Station Near Davenport, Iowa, **G. T. Shoemaker.** *Electrical World*, volume 110, August 27, 1938, pages 572–4.

64. Potomac Edison Completes New Cumberland Steam Power Plant. *Electrical World*, News Issue, volume 110, August 20, 1938, page 527.

65. Revamped Plants Conserve Investment, Gain Efficiency: Kansas City Power and Light Company, **J. A. Keeth.** *Electrical World*, volume 110, July 30, 1938, pages 278–80.

66. Today's Turbine Bought Yesterday: Unit No. 2, State Line Plant of Chicago District Electric Generating Corporation, **A. B. Clark.** *Electrical World*, volume 108, November 20, 1937, pages 1701–02.

67. Turbine Room Changes at Austin, **C. L. Elliott and J. V. Edeskuty.** *Power Plant Engineering*, volume 42, September 1938, pages 588–90.

68. Waterside Tops Again, **H. Knecht.** *Power*, volume 82, July 1938, pages 366–8.

69. Acme—A Different Top (Acme Plant Extension of the Toledo Edison Company). *Power Plant Engineering*, volume 42, November 1938, pages 684–8.

70. Austin's High Pressure Boiler (with fuel cost data), **C. L. Elliott and J. V. Edeskuty.** *Power Plant Engineering*, volume 42, November 1938, pages 700–03.

71. 53,000-Kw 3,600-Rpm Superposed Turbine for Waterside Station, **G. B. Warren.** *Combustion*, volume 9, June 1938, page 27.

72. Steam Generating Equipment at Waterside, N. Y., **H. A. Johnson and C. A. Kelting.** *Combustion*, volume 9, September 1937, page 20.

73. "Topping" 12th Street Station, Virginia Electric and Power Company, **F. H. Spies.** *Combustion*, volume 9, November 1937, page 18.

74. Waterside No. 1 Station—the Third Step in Central Station Development in New York, **G. A. Orrok.** *Combustion*, volume 9, September 1937, page 30.

75. Coal Handling Demands Reliable Service (Lynn Gas and Electric Company), **R. S. Reed and J. H. Wills.** *Electrical World*, volume 111, May 6, 1939, pages 1306–08.

76. High Pressure Extension of Detroit Edison's Delray Plant, **M. W. Benjamin.** *Power Plant Engineering*, volume 43, March, May 1939, pages 200–14; 317–31.

77. Load Center Station Topped for Base Load; Schuylkill Capability Enhanced. *Electrical World*, volume 110, November 19, 1938, pages 1448–51.

78. Operating Experience at Essex, **W. R. LaMotte.** *Power*, volume 83, February 1939, pages 92–5.

79. Plant at Load Center Again Takes Base Load; Topping Reserve Battle Creek Plant Meets Load Growth at Low Cost, **F. G. Boyce.** *Electrical World*, volume 110, November 19, 1938, pages 1442–4.

80. Power Behind Chicago—State Line Generating Station. *Power*, volume 83, April 1939, pages 190–3.

81. Rebirth of Fisk Station; Installation of Topping Turbine, **H. B. Gear.** *Electrical World*, volume 110, November 1938, pages 1452–4.

82. South Meadow's New 40,000-Kw Extension, **W. F. Ryan.** *Power Plant Engineering*, volume 43, February 1939, pages 96–102.

83. Steam Plant Expansion, Key to Narragansett Program. *Electrical World*, volume 110, November 19, 1938, pages 1445–8.

84. Duquesne Light Places New Unit in Service at Reed Steam Station. *Electrical World*, News Issue, volume 111, February 18, 1939, page 495.

85. Enlargement of L Street Steam Electric Plant of Boston Edison Company, **H. A. Gray.** Boston Society of Civil Engineers *Journal*, volume 26, April 1939, pages 85–113.

86. Essex Tops at 1,250 Pounds 950 Degrees Fahrenheit (Public Service Electric and Gas Company of New Jersey), **H. Weisberg.** *Power*, volume 83, January 1939, pages 2–5.

87. High Pressure Extension of Detroit Edison's Delray Plant, **M. W. Benjamin.** *Power Plant Engineering*, volume 43, March, May 1939, pages 200–14; 317–31.

88. Modernization of Schuylkill Station, **W. B. Morton.** *Electric Journal*, volume 35, November 1938, pages 421–6.

89. Pacific Gas and Electric Company Adds 40,000-Kw Unit. *Electrical World*, News Issue, volume 111, April 1, 1939, pages 929–30.

90. South Meadow's New 40,000 Kw Extension, **W. F. Ryan.** *Power Plant Engineering*, volume 43, February 1939, pages 96–102.

91. Ljungstrom Turbogenerator Sets at Brighton. *The Engineer*, England, May 19, 1939, pages 615–22.

92. How Gas Turbines That Work, **S. A. Tucker.** *Power*, volume 83, June 1939, pages 316–19.

93. The Combustion Gas Turbine, **Adolphe Meyer.** *Mechanical Engineering*, volume 61, September 1939, pages 645–52.

94. Economic Aspects of Energy Generation—a Symposium. *Proceedings*, American Society of Civil Engineers, December 1937:

(*a*) Progress in the Generation of Energy by Heat Engines, **G. A. Orrok,** page 1884.

(*b*) Hydro-Generation of Energy, **F. H. Rogers,** page 1893.

(*c*) Improvements in the Utilization of Energy, **J. D. Justin,** page 1912.

(*d*) Cost of Generation of Electric Energy, **Philip Sporn,** page 1925.

(*e*) Social Implications of Technological Trends in the Power Industry, **R. A. Freeman,** page 1936.

(*f*) Electric Power in Economic Perspective, **B. A. Thresher,** page 1942.

95. Electric Power Switching, **A. H. Lovell.** AIEE Transactions, volume 53, 1934, pages 147–8.

96. Switching at State Line Station, **T. C. White.** AIEE Transactions, volume 53, 1934, pages 148–56.

97. Switching at Richmond Station, **Raymond Bailey and F. R. Ford.** AIEE Transactions, volume 53, 1934, pages 156–61.

98. Switching at the Connors Creek Plant, **A. P. Fugill.** AIEE Transactions, volume 53, 1934, pages 162–8.

99. Port Washington Power Plant Design, **G. G. Post.** AIEE Transactions, volume 53, 1934, pages 264–71.

100. The Theory of Incremental Rates and Their Practical Application to Load Division, Part I, **M. J. Steinberg and T. H. Smith.** AIEE Transactions, volume 53, 1934, pages 432–45.

101. The Theory of Incremental Rates and Their Practical Application to Load Division, Part II, **M. J. Steinberg and T. H. Smith.** AIEE Transactions, volume 53, 1934, pages 571–84.

102. Voltage Regulation and Load Control, **H. C. Forbes and H. R. Searing.** AIEE Transactions, volume 53, 1934, pages 903–09.

103. A Survey of Hydroelectric Developments, **AIEE Subcommittee.** AIEE Transactions, volume 53, 1934, pages 988–93.

104. A 7,000-Ampere Station Bus (Philadelphia Electric Company), **H. L. Unland, W. B. Morton, and V. R. Bacon.** AIEE Transactions, volume 53, 1934, pages 994–1004.

105. A Survey of Hydroelectric Developments—II, **AIEE Subcommittee.** AIEE Transactions, volume 53, 1934, pages 1086–94.

106. Some Features of the Boulder Canyon Project, **E. F. Scattergood.** AIEE Transactions, volume 54, 1935, pages 361–5.

107. Circuit Breakers for Boulder Dam Line, **D. C. Prince.** AIEE Transactions, volume 54, 1935, pages 366–72.

108. Engineering Features of the Boulder Dam-Los Angeles Lines, **E. F. Scattergood.** AIEE Transactions, volume 54, 1935, pages 494–512.

109. Engineering Features of Boulder Dam and Power Plant, **L. N. McClellan.** AIEE Transactions, volume 54, 1935, pages 583–94.

110. Rehabilitation of the Connors Creek Plant, **R. E. Greene.** AIEE Transactions, volume 54, 1935, pages 610–17.

111. Design and Operation of Huntley Station No. 2, **H. M. Cushing.** AIEE Transactions, volume 54, 1935, pages 632–45.

112. 287-Kv Boulder Dam Disconnecting Switch, **A. J. Bowie and C. P. Garman.** AIEE Transactions, volume 55, 1936, pages 582–9.

113. Circuit Breakers for Boulder Dam Line, **H. M. Wilcox and W. M. Leeds.** AIEE Transactions, volume 55, 1936, pages 626–35.

114. Switchboards for Boulder Power Plant, **L. N. McClellan, H. J. A. Peterson, and C. P. Garman.** AIEE Transactions, volume 56, 1937, pages 224–36; 244.

115. The Columbia Basin Project, **A. F. Darland.** AIEE Transactions, volume 56, 1937, pages 1339–45.

116. Modernization of L Street Station of the Boston Edison Company, **C. A. Corney and W. A. Edson.** AIEE Transactions, volume 58, 1939, pages 770–8.

117. Modernization of Switch House Design of Stations of Consolidated Edison Company, **A. M. de Bellis.** AIEE Transactions, volume 58, 1939, pages 752–60.

118. Modernization of Switch House Design, **H. E. Strang and W. M. Hanna.** AIEE Transactions, volume 58, 1939, pages 747–51.

119. Reconstruction of Switching Facilities at Essex Generating Station, **D. W. Taylor.** AIEE Transactions, volume 58, 1939, pages 761–70.

Air Breakers for Power-House Drives

A COMPACT GROUP of seven Westinghouse De-ion air circuit breakers, with interrupting rating of 13,850 amperes, controls the 3-phase 60-cycle 4,150-volt circuits for auxiliary drives serving a 200,000-pound-per-hour boiler and the 20,000-kw turbine at the Blount Street station of the Madison (Wis.) Gas and Electric Company. Based upon ten months' service, the maximum number of operations of any one breaker has been about 553 and the number of average automatic openings of all breakers 341.

These breakers were selected instead of conventional types because of: (1) greater safety; (2) elimination of oil storage, piping, and filtering equipment; (3) performance of more operations without maintenance; (4) reduction of inspection and repair expense; and (5) cleanliness. To date, maintenance and replacement of parts has been appreciably less than with oil breakers in comparable service. Because such air breakers can be placed close together without danger, the company was able to place them in a vault under the floor of the boiler room, as shown in the accompanying illustration. As a precaution, the top of the breaker structure is shielded by the slanted roof shown.

The Triple Alliance in Electrical Insulation

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MEMBER AIEE

A review of progress in electrical insulation achieved by the combined efforts of physicists, chemists, and electrical engineers

IF AIR were not an insulator, the generation, transmission, and utilization of electric power would be beset with almost insurmountable difficulties. For example, lamp sockets or any other exposed portion of the electric wiring in homes would support no voltage and would carry no current to lamps or other electrical appliances. In the powerhouse conditions would be even worse, unless perhaps the generators were placed in a high vacuum. If humans lived in a water medium, as fish do, the comforts electricity has provided almost certainly never would have been known. Perhaps the only advantage of a conducting medium would be the complete elimination of lightning, for then the clouds would not become charged. Conducting air, however, would be a high price to pay for removal of the danger of lightning.

In most respects air and several other gases are among the best insulators. In any practical sense the conductivity, power factor, and loss factor of air are zero when it is not stressed above its ionization voltage. Air, as the dielectric between the plates of a capacitor, is therefore used as the standard in all insulation testing. An air capacitor is the fundamental and basic element of any dielectric-loss or power-factor-measuring circuit in terms of which all materials are measured. But now one may be asked, "Why is there need for other insulating materials if air has such good properties?"

The answer is twofold: (1) The breakdown strength of air is somewhat lower than that of most liquid and solid dielectrics, and thus with air larger spacings between conductors are required; and (2) since air is a gas and therefore will support no weight, solid dielectrics are necessary to support the weight of the conductor. The breakdown strength of air at atmospheric pressure is 30 kv per centimeter when the electrodes used give a uniform field. This breakdown strength almost never is realized in practice, because uniform field conditions are rare and a factor of safety must be used.

The bare conductors of a 220-kv open transmission line are placed approximately 25 feet apart. In a power cable built for this same voltage, the thickness of oil-impregnated paper is less than $2\frac{1}{2}$ inches instead of the 25 feet of air. In the construction of any piece of electrical equipment from the largest powerhouse generator of well over 100,000 horsepower to the smallest electric-razor motor of less than $\frac{1}{100}$ horsepower, the space for insulation is limited. Hence, ever since the birth of the electrical industry a little over 50 years ago, the quest has gone on for new materials that would stand for longer periods of time a higher voltage per unit of thickness. The development of materials having not only high breakdown strength, but also the other desirable qualities of a good insulator—(1) low conductivity, (2) low dielectric loss, (3) low or high dielectric constant depending on application, (4) good mechanical properties, and (5) good thermal and time stability—has occupied the attention of many scientific and technical men. These men are physicists, chemists, and electrical engineers—the triple alliance in electrical insulation. Thus, problems of electrical insulation transcend the boundaries of several sciences.

History of Electrical Insulation

The early history of electrical insulation or dielectrics was made almost entirely by physicists. It began with the beginning of electrostatics in the 18th century and extended through most of the 19th century. With it we can associate such illustrious names as Franklin (1706–1790), Cavendish (1731–1810), Coulomb (1736–1806), Faraday (1791–1867), and Maxwell (1831–1879). Of these, Maxwell made theoretical contributions of the greatest importance and the others made equally important experimental contributions. These workers provided the background for the mass of work now reported in technical and scientific literature. Perhaps the first engineer to attract attention in this field was Siemens in Germany, who in 1864 observed that heating in capacitors was associated with a departure from the 90-degree phase relationship between alternating current and voltage. This was at the very beginning of electrical engineering, when telegraphy was the sole problem. The major work on dielectrics at that time was still being doing by physicists.

With the birth of the electric-power industry in the early 1880's, and with the realization of the advantages of high-voltage transmission which followed in the next ten-year period, more and more engineers became interested in dielectrics and their performance as insulators. The literature published since that time reveals an enormous amount of experimental data giving the electrical properties of many insulating materials together with scattered attempts to check or modify the older theories, particularly Maxwell's[1] theory of dielectric absorption. By 1900

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1. For all numbered references see list at end of article.

most of the physicists had become distracted from the field of dielectrics through the discovery of X rays by Roentgen in 1895, the discovery of radioactivity by H. Becquerel in 1896, and the discovery of the electron by Sir J. J. Thompson in 1897, thus leaving the engineer to his accumulation of empirical data. The physicists saw greener pastures in these other fields and perhaps rightly so. However, they have never entirely deserted the field of dielectrics. At present, many physicists can be found doing important fundamental work on dielectrics.

Chemists may be said to have entered the field in 1912, when P. Debye[2] published his first paper on his theory of polar molecules. It was not until the 1920's, however, that this new fundamental theory received the attention that it deserved, undoubtedly because of the World War. It was then that chemists began to realize that much could be learned about the structure of molecules by measurement of dielectric constants and application of Debye's theory. The literature on both the experimental and theoretical sides began to develop rapidly and today this phase of dielectrics is of tremendous interest to chemists, physicists, and engineers.

In 1909, the synthesis of Bakelite was first described in a historic paper by Doctor Leo H. Baekeland.[3] Since that time, and more particularly since the 1920's, the organic chemist has synthesized new materials in the form of resins at an amazing rate. These have replaced to a large extent the natural resins formerly used in the electrical industry. Large quantities of these resins both in the form of solids and varnishes or impregnants for fibrous materials are used. Thus, physicists, chemists, and engineers all have contributed to the common knowledge of dielectrics. It is, therefore, not illogical to find representatives of all these branches of science working together in every important laboratory where dielectric research is carried on. This triple alliance is also well represented in a national organization, the Conference on Electrical Insulation of the National Research Council, with its subcommittees on chemistry and physics.

Much of the work that relates or might relate to dielectrics, however, is not done in laboratories where these three groups are working together, but in laboratories where only one group is working alone. Many chemists are working in laboratories synthesizing materials for almost every conceivable purpose. In other laboratories physicists and physical chemists investigate the structure and fundamental behavior of matter. These groups are not always familiar with electrical-engineering problems in the application of materials as insulators. A closer relationship of the various groups undoubtedly would promote more rapid progress.

Nature of a Dielectric

Perhaps the best definition of an insulator is that implied by Faraday when he segregated the materials then available into two classes according to whether they did or did not conduct electricity. On the basis of the well-established theory of matter, the important condition that makes a material an insulator or dielectric is that the electrons and other charged particles of which it is composed are held in equilibrium positions by certain forces characteristic of the material. When a field or a voltage is applied these charges are displaced, the negative charges in one direction and the positive in the opposite direction, so that the dielectric is strained elastically, so to speak. When the field is removed, however, all charges return to the original equilibrium positions. In a conductor, according to the electron theory of matter, it is presumed that the electrons are instantly free to move when a field is applied.

On the basis of the newer quantum theory, the difference between conducting and nonconducting crystals is explained by considering various zones of energy levels of valence electrons.[4] The energy spectrum for the valence electrons is illustrated in figure 1. The shaded regions are allowed and the clear regions are forbidden energies that an electron may have. The allowed energies correspond to finite, single-valued, and continuous solutions of the Schroedinger wave equation, whereas the forbidden

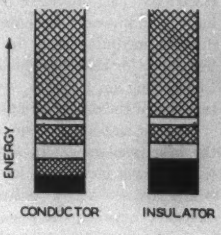


Figure 1. Typical energy spectrum for valence electrons in a conductor and an insulator

energies do not correspond to finite, single-valued, and continuous solutions. The Schroedinger wave equation is the fundamental equation of wave mechanics. Conduction takes place in the crystal as a result of the transference of an electron from one energy level to another. This can occur only when not all of the energy levels in the shaded region are occupied by electrons. The black portion of the lowest shaded or allowed band in figure 1 indicates the presence of electrons. The diagram shows that the most important difference between a conductor and an insulator is that in the case of the former only part of all of the energy levels in the lowest allowed band are occupied by electrons, whereas in the case of the latter, all of the energy levels in this band are occupied by electrons. The mechanism of conduction in the two cases can be made clearer by the following rather crude analogy: The valence electrons may be pictured as bricks in a wall. In the case of a conductor the bricks are stacked only part of the way to the roof, the roof corresponding to the rather wide forbidden (clear) region just above the lowest allowed band of energies. Now when a small voltage is applied to a conductor, electrons are raised in energy from the black to the shaded region where they are free to move; that is, bricks are easily lifted from the top of the wall and moved horizontally. In the case of an insulator, however, the bricks corresponding to the valence electrons are stacked in such a way that the resulting wall extends to the roof or to the base of the forbidden region. In order for conduc-

tion to take place, a sufficiently large voltage must be applied to the insulator to raise the bricks through the roof or through the forbidden region to the next shaded or allowed band. It has been calculated that a voltage stress of approximately a million volts per centimeter is necessary to obtain an appreciable current in an insulating crystal such as sodium chloride. Breakdown of the crystal occurs when enough electrons are lifted through the forbidden region to produce an avalanche of electrons in the next allowed band.

The foregoing are only the physicist's pictures of a dielectric, and perhaps they are not completely truthful. They do, however, represent the limit of existing knowledge. Insulating properties of a material are not always determined by the kind of atoms in the material. All metals are known to be conductors or at least semiconductors; but mica, an excellent insulator, contains atoms of aluminum, potassium, and magnesium. The structure or manner of arrangement of the atoms within the material also has an important bearing on the dielectric properties.

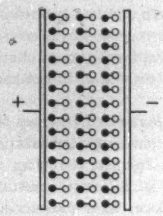


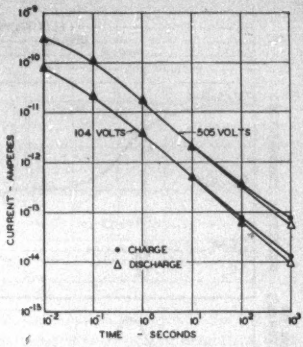
Figure 2. Dielectric between plates of a capacitor

All pure hydrocarbons are good insulating materials; but when, for example, oxygen is introduced into the molecule to form alcohols, ketones, or acids, the insulating properties are greatly impaired. The size of molecule often may influence also the electrical behavior. Phenol and formaldehyde in themselves have poor insulating properties, but when they are reacted with each other and subsequently polymerized, they form the very large Bakelite molecule which has long been used as an insulator. The oxygen, or rather the hydroxyl group in Bakelite, however, has some influence on its electrical behavior. The dielectric losses in this material are known to be higher than in the pure hydrocarbon resin styrene which has the lowest losses of all known resins. These points are discussed in more detail by Hartshorn and co-workers.[5]

Conduction, Loss, and Dielectric Constant

All insulators pass some current, however small, when voltage is applied across them. Gases perhaps should be excepted, because the conduction is almost immeasurably small below the critical ionization voltage. To see the nature of conduction in insulators, consider the somewhat crude picture of a dielectric between the metal plates of the capacitor shown in figure 2. The dielectric is divided into the fundamental structural units, which may be

Figure 3. Charge and discharge (d-c) for mica at two voltages (Voglis)



either atoms or molecules. Only a few of these units are shown in the much magnified picture. When a unidirectional voltage is applied, with the polarity indicated, the electrons are displaced instantaneously from the positively charged nucleus with which they are associated. This corresponds to an instantaneous current flow through the supply lines, which results in the charging of the capacitor. In gaseous dielectrics, this instantaneous flow of current takes place, but the current then falls to zero in an exceedingly short time and no further current can be detected, even with the most sensitive galvanometer.

In solids, conversely, a current flow can be measured which decreases with time for minutes, hours, and in some instances even days after the voltage is applied, until the final constant conduction current is reached; it then persists indefinitely. This is illustrated in figure 3, which shows current curves for mica as obtained by Voglis.[6] From this figure, it is apparent that for the two charging voltages indicated the current is still decreasing after more than fifteen minutes and the final constant current has not yet been reached. The initial rush of current is not shown in figure 3, because it is over before even the 0.01 second at which time the measurement is begun. This decreasing current with time has been called "dielectric absorption" because it is believed that charge gradually "soaks" into the dielectric. The final constant current is true conduction current, probably of ionic nature, which flows through the dielectric.

Returning to figure 2, if the voltage is removed and the two plates of the capacitor connected together, thus discharging it, the instantaneous rush of current is in the opposite direction and the centers of the positive and negative charge again coincide. The absorbed charge flows out of the dielectric as illustrated in figure 3 by the discharge curves, and nearly all the charge absorbed on charging is returned on discharging. The charge and discharge curves deviate only at the long time end when the final conduction current becomes significant. This latter is, of course, not returned on discharge.

Maxwell[1] was the first to supply a mechanism for this phenomenon of residual or absorbed charge. He assumed that all dielectrics are heterogeneous and showed that volume charges can accumulate at the boundaries or inter-

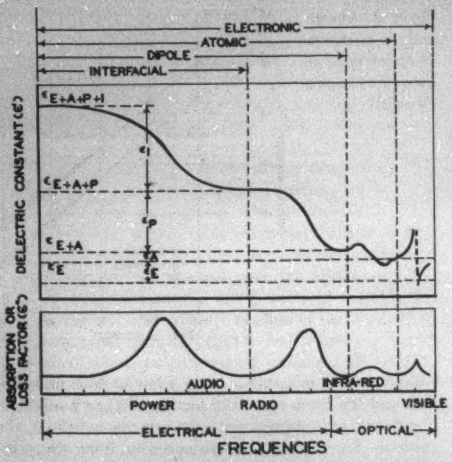


Figure 4. Schematic diagram showing variation of dielectric constant and dielectric absorption with frequency (Murphy and Morgan)

faces of the various components of the dielectric. This is a process that requires time. Maxwell probably pictured even slight impurities as heterogeneities. The fact remains, however, that even the purest solids, such as quartz, show dielectric absorption. Even to this day, nobody has found an explanation better than that given by Maxwell.

In liquids the action is somewhat different. On charge a current decreasing with time can be observed which gradually approaches a final constant value. On discharge, however, when the initial rush current is over, no further current is observed, thus indicating that dielectric absorption is absent. The decreasing current with time on charge is believed to be due to motion of ions or ion clusters, but practically nothing is known of the nature of the ions that are involved. An enlightening discussion of conduction in insulating oils is given by Whitehead.[7]

One of the most important characteristics of an insulator is dielectric loss under alternating current. This usually is measured by means of special bridge circuits in terms of power factor or loss factor. Power factor is defined as the ratio of the energy loss caused by oscillation of charges (or rotation in the case of polar molecules) in the dielectric to the product of volts applied and amperes flowing through the dielectric. Loss factor is the product of dielectric constant and tangent of the loss angle. Mathematically, power factor is defined as the sine of the loss angle. It is possible to compute the power factor approximately using the value of d-c conductivity corresponding to the time of half the a-c cycle. For 60 cycles this would correspond to the conductivity roughly 0.01 second after the application of voltage. A more exact method of computing power factor from the charging-current curve is given by Whitehead and Banos.[8] Power factor is important, not only in itself, but because it has a significant bearing on breakdown strength.

When a voltage is applied to a dielectric and a separation of charges takes place, the dielectric is said to be polarized. The amount of this charge separation is proportional to the dielectric constant. In an alternating field, the dielectric is alternately polarized in one direction and then in the opposite direction, thus bringing about an oscillation of charges.

There are several types of polarizations which are effective at different frequencies because these polarizations have different relaxation times. The instantaneous polarization discussed in connection with figure 2 is caused by the distortion of the orbital electrons with respect to the atomic nucleus and is called electronic polarization. If the dielectric is polar, there will be an additional contribution to the total polarization, because of the orientation of the polar molecules with the field. This is called dipole polarization. A third type of polarization is called atomic polarization, regarding which little is known. It may arise by the displacements of ions in an ionic crystal such as sodium chloride. The fourth and last type of polarization is that ascribed to heterogeneous dielectrics. Since it is believed to be caused by a formation of charge at the interfaces of the composite dielectric, it has been called interfacial polarization.

For each of these polarizations there is a frequency the period of which is too short for the particular polarization mechanism to respond. In this frequency region an anomalous dispersion or falling off of dielectric constant with increase in frequency takes place. The various dispersion regions are indicated approximately in figure 4 which also has been discussed by Murphy and Morgan[9] and Gemant.[10]

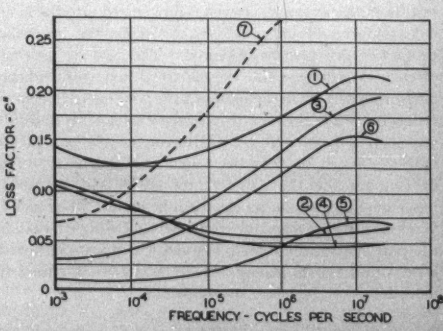


Figure 5. Loss-factor characteristics as a function of frequency for plastics, showing effect of cellulose molecules and mineral fillers (Yaeger)

1—Urea formaldehyde containing cellulose filler
2—Unfilled phenolic resin
3—Phenolic resin containing 60 per cent wood flour
4—Phenolic resin containing mica dust or talc filler
5—Unplasticized ethyl cellulose
6—Laminated paper phenolic resin
7—Cellophane

The upper part of figure 4 shows that the slowest type is the so-called interfacial polarization. With this type of polarization may be included that caused by oscillation of electrolytic ions. It fails to respond beyond the audio-frequency region, the upper limit of which is approximately 20,000 cycles. Dielectric-constant dispersion may occur at any part of this region. Next is dipole polarization, which can respond from the upper radio frequency of about 10^8 cycles down. The frequency at which the dispersion occurs depends on the viscosity of the medium in which the dipole is rotating and on the radius of the molecule. The dispersion of atomic polarization for alkali halide crystals has been found to be in the infrared region as shown in figure 4. In the sense of any electrical frequency this is an instantaneous polarization. Electronic polarization covers the widest frequency range with the dispersion region in the optical-frequency range. The dielectric constant for electronic polarization can be computed from refractive index measurements by the use of Maxwell's law ($\epsilon = n^2$) which states that the dielectric constant equals the square of the refractive index. For many materials such as the pure nonpolar hydrocarbon liquids the dielectric constant indeed can be approximated by squaring the refractive index. For such materials the dielectric constant obviously is independent of any frequency in the electrical range, and the polarization is almost entirely electronic.

The lower part of figure 4 shows that a maximum of energy loss is associated with each dispersion region shown in the upper part of the figure. These manifest themselves as power-factor maxima in the electrical-frequency range and as absorption regions in the infrared and optical-frequency range. This has the obvious practical significance that a material should not be used in the frequency region where the energy-loss maximum appears. An example of this is found in the work reported by Yaeger.[11] He has measured the loss factor and dielectric constant of a number of plastics over a range of frequency from 10^3 to 3.5×10^7 cycles. He found that when cellulose is incorporated in the resin in whatever form, such as wood flour and paper or cellulosic resin, a loss factor maximum appeared at approximately 10^7 cycles. Some of Yaeger's results are shown in figure 5. A dielectric-constant dispersion was observed at the same frequency, but is not shown. Figure 5 shows also that when such mineral fillers as mica dust and talc are added, the maximum does not appear. The dashed curve (7) of figure 5 is for Cellophane as obtained by Stoops,[12] and is added to show that this cellulosic material also appears to have a maximum at the same frequency. The explanation offered for the loss-factor maxima in cellulose derivatives is that the hydroxyl groups rotate about the long cellulose chain, and for this rotation 10^7 cycles is the characteristic frequency. The practical significance is that cellulose derivatives should not be used as very high-frequency insulation.

This discussion might be carried much further. The properties of conductivity, dielectric loss, and dielectric constant have been discussed only in the most general way. The dielectric constant behavior of polar molecules has been and still is of much interest to the chemist and physicist because of the relation between dielectric constant and molecular structure. But the insulation engineer also is extremely interested in these matters.

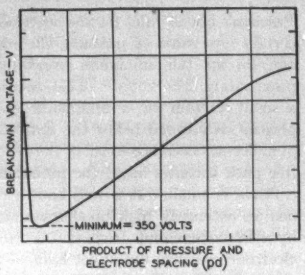


Figure 6. Breakdown strength as a function of product of pressure and electrode spacing

Electric Breakdown or Dielectric Failure

Breakdown strength is perhaps the most important property of dielectrics. It has been investigated chiefly by engineers and physicists. The subject is far too large to be adequately treated in a discussion of this kind, and hence only a cursory examination of the state of existing knowledge is given here. Unfortunately, little is known of the mechanism of breakdown of liquids and solids mainly because of the lack of intimate knowledge of the liquid and solid states. With the quantum theory physicists are renewing their attack on the solid state in particular, and any information which the atomic physicists obtain will be helpful. Because of the greater distances between atoms or molecules in gases, knowledge of the conduction and breakdown mechanisms for these materials is much greater than for the more condensed states of matter. The theory for gases is fairly well developed. Knowledge of liquids and solids is based almost entirely on experimental data.

In gases there are always positive and negative ions which number about 600 per cubic centimeter each for ordinary air.[13] With the application of voltage these are accelerated and make collisions with neutral molecules. As the breakdown voltage is approached these collisions become severe enough to rupture neutral atoms, thus forming other charged particles. This process goes on in a cumulative way and breakdown results through the initiation of a self-maintained discharge. Townsend[14] has expressed the current produced in this ionization-by-collision phenomenon by means of an exponential, thus illustrating its cumulative nature.

Another important relation describing breakdown in gases is Paschen's[15] law, which states that the breakdown strength of a gas is proportional to the product of the distance between electrodes and the pressure; or for fixed electrode spacing, the breakdown strength is proportional to the pressure. Since the mean free path of the atoms or molecules in a gas is inversely proportional to the pressure, this is equivalent to saying that the breakdown strength is inversely proportional to the mean free path. The experimental data are illustrated in figure 6. Apparently

Paschen's law is valid for the intermediate region. At a certain low value of pressure, the curve has a minimum and for air this minimum breakdown strength is approximately 350 volts. This occurs at a pressure of a small fraction of a millimeter of mercury. As the pressure is lowered below the critical value, the number of molecules becomes so small that even though the mean free path becomes large, the probability of ionization by collision is small. It is well known that a high vacuum has an extremely high breakdown strength limited only by electron emission from the electrodes. For ordinary electrode spacings the upper limit of the validity of Paschen's law is approximately ten atmospheres pressure. Above this, the curve begins to flatten out because of space charge and electrode effects. Some recent work on the breakdown strength of compressed gases is described in a paper by Howell.[16]

Passing now to solids and liquids, von Hippel[17] has shown that Paschen's law for gases cannot be extrapolated to explain the behavior of these condensed insulators. Assuming breakdown strength of air to be 30 kv per centimeter and average density of liquids and solids to correspond to about 2,000 atmospheres pressure, solids and liquids should stand about 5×10^7 volts per centimeter. Experimental values for such insulators, however, lie in the range of 10^5 to 10^6 volts per centimeter. An attempt to explain this discrepancy has been made by von Hippel[17] in a theoretical and experimental study of ionic crystals such as the alkali halides. He concluded that breakdown in the alkali halides is electronic and that the mechanism of cumulative ionization is different from that in gases. He concluded further that cumulative ionization creates space charges which distort the field and that these space charges play a dominating role in the breakdown of solids and liquids. As an illustration of the disagreement among those working in this field, the work of Inge and Walther,[18] who also made a study of electric breakdown of alkali halide crystals, may be cited. They studied the breakdown strength over a range of temperature and found that it decreased markedly with increase in temperature. They conclude that breakdown in alkali halide crystals is not electronic, at least at the higher temperatures, and give evidence in support of heat breakdown.

The theory for heat breakdown was originally developed by Wagner.[19] He assumed that one part in the dielectric has a higher conductivity than all other parts and by the following reasoning shows that breakdown should take place at the point of highest conductivity: Heat is generated at the high conductivity point at a faster rate than it can be dissipated, and because of the positive temperature coefficient of conductivity in dielectrics, this results in cumulative heating. Once cumulative heating is established the dielectric must fail, for it is literally melted or burned because of the high temperature developed in this way. The theory undoubtedly explains the breakdown of solids in a qualitative way, particularly in high-loss materials or at high temperatures. On the basis of this theory, one would expect a decrease in breakdown strength with increase in temperature and also with increase in conductivity and dielectric loss. That this is true has been demonstrated by Inge and Walther[20] in their work on glass. Their curves for two glasses of different resistivities are given in figure 7 in which the logarithm of the breakdown voltage is plotted against the reciprocal of absolute temperature, showing that at low temperatures the breakdown strength is independent of temperature. In this region the breakdown is believed to be disruptive, that is, the forces of cohesion between atoms or molecules are overcome. In the high-temperature region, the logarithm of the breakdown strength may be seen to decrease linearly with the reciprocal of the absolute temperature. In this region heat breakdown prevails. Intermediate between these two there is a transition region where both effects apparently enter into the breakdown process.

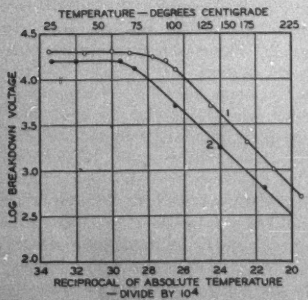


Figure 7. Influence of temperature on breakdown voltage for two glass samples (Inge and Walther)

1—Resistivity at 200 degrees centigrade 2.09×10^7

2—Resistivity at 200 degrees centigrade 4.06×10^8

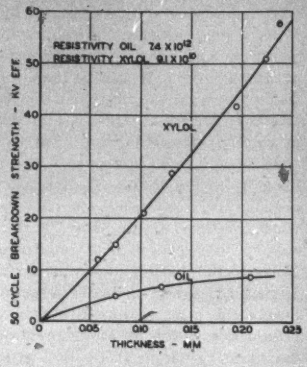


Figure 8. Breakdown versus thickness of glass showing influence of testing medium (Inge and Walther)

Figure 7 shows also that the glass with the higher resistivity has the higher breakdown strength. This is true in general, and particularly of solids. It should now be evident why engineers insist on low-conductivity or low-power-factor materials for use as high-voltage insulators.

It is well known that the apparent breakdown strength of insulation decreases with increase in thickness of the sample under test. This is caused by the voltage stress concentration at the edges of the electrodes. The sharper the edges of the electrodes the greater the nonuniformity of the field and the lower the apparent breakdown strength.

It has long been known that this edge effect can be sup-

pressed and that then the breakdown strength increases linearly with the thickness. One way to suppress the edge effect is to use a test sample in the form of a double concave lens with spherical electrodes fitting the concavities. This results in a thicker layer at the edges which assures breakdown at the bottom of the spherical cavity where the field is uniform.

Another method of suppressing edge and contact effects is that used by Inge and Walther,[21] and consists in immersing the test specimen in xylol. The effectiveness of this method is illustrated in figure 8. It shows that when the usual low-conductivity oil is used as the medium surrounding the test specimen, the breakdown strength is far from linear with thickness, but when the higher conductivity xylol is used, a linear relation results. The higher conductivity of the xylol effectively removes the stress concentrations. The same effect can be accomplished by adding a small proportion of acetone or aniline to transformer oil.

It should be easy to see why there is usually so much discrepancy in breakdown tests on the same material when the testing medium can influence the results as much as 500 per cent. Still other effects have a marked influence, of which perhaps nonuniformity of the test specimen is most serious. For liquids the situation is still more complicated. A drop of water, a fiber or dust particle drawn between the electrodes can markedly influence the breakdown. For both liquids and solids the rate of rise of voltage is also important. So many factors can affect the breakdown that a test result without a statement of test conditions has little meaning.

Stability of Insulators in Service

In general the weakest portion of electrical equipment is the insulation, because insulators are comparatively fragile and more susceptible to deterioration than other materials entering into the construction. Unfortunately, also, most insulators are organic, which places a serious temperature limitation upon them. The ability of a material to maintain good insulating properties over a long period of time under service conditions thus becomes extremely important. "How long will the material last?" is a question often asked. To answer it engineers have devised many types of accelerated life or aging tests, where temperature or voltage or both are elevated above normal in order to obtain results in a reasonable time. The problem of interpreting such test results in terms of service life has been exceedingly difficult.

Where inorganic insulators such as mica and fiber glass can be used this problem is somewhat simplified; but even here the flakes of mica and the glass fabric must be bonded together or filled with an organic material having a definite temperature limit. The recent development of glass textiles[22] represents an important contribution to the insulation field, but a still more important contribution is yet to be made, namely, the development of an inorganic plastic bonding material with electrical properties comparable with those of the low-alkali glasses and mica.

As has been indicated already, most insulations are organic, and most of these take the form of cellulose, petroleum oils, and resins or varnishes. All three are used in the transformer and the first two in high-voltage cables. Oil and cellulose often are combined because they not only possess excellent electrical properties, but also very desirable mechanical properties. The two in combination and each alone have been the subject of many investigations by both chemists and engineers. The noteworthy improvement in the performance of oil-impregnated paper as a high-voltage insulation is in no small measure due to such important work as has been done by Whitehead[23] and his co-workers. Much of this work, however, has been of a physical nature, and if further rapid progress is to be made the services of the chemist appear indispensable, for insulation deterioration is to a large extent a chemical problem.

Cellulose, reasonably free of impurities, possesses good thermal stability. Since it is a porous material it cannot be used alone, but must be filled with some material that will replace air and prevent the entry of moisture. Considerable evidence has been supplied recently that most of the deterioration of cellulose is caused by the products of deterioration of the impregnant. An example of this effect is found in the work of Clark[24] who made accelerated stability tests on paper impregnated with various oils. Figure 9 shows some of his results with a normally refined oil and a highly refined oil. The power factor of the latter is seen to increase very rapidly, which is probably caused by the increase in acidity of the oil combined with the effect of this acidity on the paper. The normally refined oil builds up no acidity during the test and no serious increase in losses is noted.

In the application of materials as insulators, the maintenance of good mechanical properties for long periods of time often is quite as important as a similar maintenance of good electrical properties. That the mechanical properties of cellulose can deteriorate very rapidly and seriously when aged in oil exposed to air is shown in figure 10

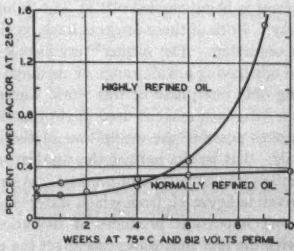


Figure 9. Dielectric instability of linen paper impregnated with highly refined oil (Clark)

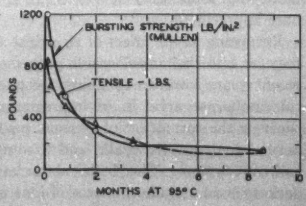


Figure 10. Deterioration of the mechanical properties of fuller board in oil open to air (Hill)

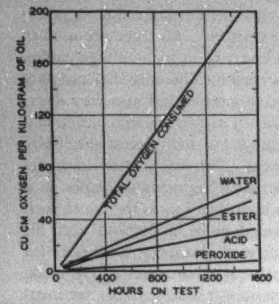


Figure 11. Oxygen balance for oil aged in closed vessel (Larsen)

taken from a recent paper by Hill,[25] in which temperature limits are discussed. Strong evidence that products of oxidation of resins may also destroy the mechanical properties of cellulose is given by Weber.[26] He shows that this action on cellulose can take place even at room temperature over a period of years. It appears, therefore, that much of the deterioration of cellulose is caused by the impregnant. The mechanism by which this secondary deterioration of cellulose takes place has not as yet been fully explained. The deterioration of cellulose in itself and the effect of impurities also require further study.

In the study of deterioration of petroleum oils, two important effects have been isolated. One is the effect of oxygen on the oil, and the other the effect of electrical discharge. Much research effort has been expended on the study of oxidation of petroleum oils, and perhaps this has been out of proportion to the progress made. These studies have been difficult because of the complex nature of petroleum. So far the oxidation mechanism is still a matter of speculation. One of the more important current researches on oils is that being carried out at the Massachusetts Institute of Technology. A similar work on the combined behavior of cellulose and oils under electrical stress is being carried out at The Johns Hopkins University. Both of these projects have received wide industrial sponsorship. The former[27] involves a fundamental study of oils having a wide range of chemical constitution. Citing only one phase of this work, Larsen[28] has found that the Grignard reagent used in conjunction with other tests makes possible the evaluation of the oxygen balance for oils; that is, the part of the total oxygen consumed that enters into each type of product. A typical case of this is given in figure 11, from which water is seen to be one of the most important products of oxidation. This, together with the fact that water can affect the electrical properties more than some other oxidation products, has not always been appreciated.

Returning to the effect of electrical discharge on oils, it may be said that considerable progress has been made in recent years toward explaining the phenomena. Electrical discharges arise in oil-impregnated-paper insulation through the formation of gaseous pockets as a result of normal temperature cycles and accompanying expansion and contraction. The electrical discharge formed in these pockets is an abundant source of ions which under the influence of the field bombard the oil molecules. The products are usually hydrogen, hydrocarbon gases, and waxy solid polymerization products known as "X-wax." It has been shown that the degree of refining of the oil strongly influences the amount of gaseous products given off by an oil.[29] In figure 12, the pressure rise in a closed system is plotted against time of subjection to an ordinary low-pressure electrical discharge. It may be observed that the highly saturated solvent-refined oil gives off considerably more gas than the highly aromatic extract obtained in solvent refining.

The refined saturated oils, however, possess good stability to oxidation and hence are desirable from this standpoint. The addition of small amounts of certain aromatic hydrocarbons decreases markedly the amount of gas given off by saturated oils.[25] This is illustrated in figure 13, which shows the effect of adding diphenyl to a solvent refined oil. Such methods, while valuable as palliatives in prolonging the life of insulation, do not represent a complete solution of the problem. So far no derivative of petroleum has been isolated that is either entirely stable to oxidation or immune to the effects of electric discharge.

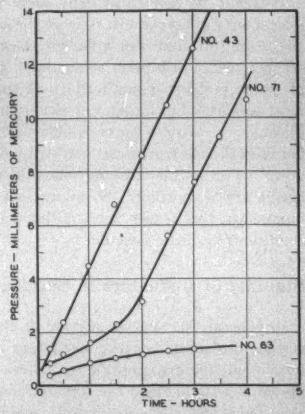


Figure 12. Gas evolution under electric discharge as influenced by degree of refining

No. 43 — Highly saturated solvent-refined oil

No. 71—80 per cent solvent-refined oil plus 20 per cent solvent extract

No. 63—Highly unsaturated solvent extract

A striking example of the results of chemical effort expended in the field of insulation is the development of synthetic liquid dielectrics. Some years ago a demand arose for fireproof insulating liquids for use in certain hazardous installations of electrical apparatus. Fortunately, this demand came at a time when the necessary basic hydrocarbons, namely, the benzene derivatives, were available as by-products in the chemical industry. When this problem was placed before the chemist, he soon recognized the inherent stability of these benzene derivatives and that they could be made noninflammable by replacing a sizable fraction of the hydrogen atoms with halogen atoms. The physical properties required for various applications were obtained by properly blending the various halogenated benzene derivatives. Some of the compounds used are chlorobenzene, chlorodiphenyl, and alkyl

chlorobenzene; the number of chlorine atoms in each may vary somewhat. These materials, however, have replaced only a small part of the petroleum oils used in transformers. Their cost is still high compared with that of petroleum. Chemical history, however, has shown repeatedly that cost reduction in synthetic products is merely a matter of time.

Halogenated hydrocarbons incidentally have found a more important use as an impregnant for the paper dielectric used in capacitors. The dielectric constant of oil-impregnated paper formerly used is approximately 3 and that of paper impregnated with these synthetic liquids is about 4.5. This higher dielectric constant combined with the discovery that these synthetic liquids enable operation at higher voltage stresses, has enabled engineers to reduce the physical size of capacitors to half that of earlier capacitors with oil-impregnated-paper dielectric. Operation at higher voltages is made possible by better

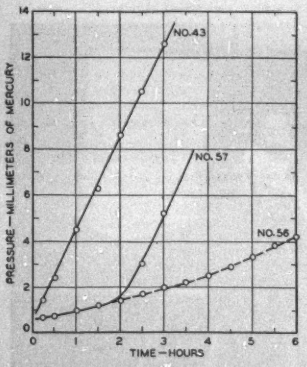


Figure 13. Gas evolution under electric discharge showing effect of adding diphenyl to oil

No. 43—Saturated solvent-refined oil at 27 degrees centigrade

No. 57—Oil plus 5 per cent diphenyl at 27 degrees centigrade

No. 56—Oil plus 5 per cent diphenyl at 60 degrees centigrade

voltage distribution between impregnant and paper. For two materials used in such a combination the stress divides itself in the inverse ratio of dielectric constants. The dielectric constants of cellulose fiber, halogenated hydrocarbons, and oil are approximately 6, 4, and 2.2 respectively. Thus, in oil-impregnated paper the oil bears several times as much stress as the paper fibers, which is not an ideal condition. The voltage distribution becomes better when the oil is replaced with the polar liquid having a dielectric constant more nearly equal to that of paper.

The dielectric properties of these chlorinated hydrocarbons have been investigated extensively. Figure 14, taken from a paper by Hill,[20] illustrates beautifully the power-factor and dielectric-constant behavior as influenced by temperature and frequency that is typical of polar materials. At low temperatures the material is too viscous for the permanent dipoles to rotate, and the dielectric constant is essentially that corresponding to the electronic polarization. As the temperature increases the polar molecules begin to rotate more and more freely because of the lower viscosity until the maximum contribution is reached. As the temperature is further increased, however, the thermal motion of the molecules acting as a restoring force disturbs the orientation of the dipoles. This effect increases with the temperature in accordance with the Debye theory and explains the slow decrease in dielectric constant. Very sharp power-factor maxima are observed in the dielectric-constant dispersion regions. These maxima are shifted to higher temperatures as the frequency increases. The 60-cycle power-factor may be seen to increase again above 60 degrees centigrade. This is caused by the oscillation of ions which are presumably of an electrolytic nature. No similar increase in power factor is observed at 1,000 cycles because these ions are of such size that they no longer can follow this high frequency. Obviously, any practical liquid for capacitors is always blended so that the dielectric-constant dispersion and power-factor maximum are below the operating temperature.

Liquids of this type with even higher dielectric constant and greater stability are desirable. In the case of solids,

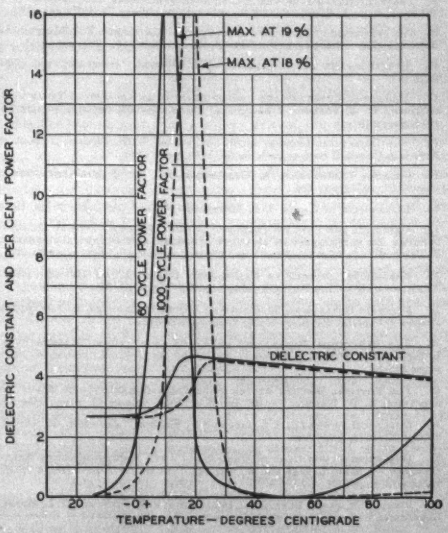


Figure 14. Typical behavior of power factor and dielectric constant of a polar dielectric liquid (Hill)

resins are sought that combine good electrical properties with stability at higher and higher temperatures. Organic materials appear to have a definite upper temperature limit and even the best of them fail when subjected continuously to temperatures as high as 150 degrees centigrade. With present trend toward higher temperatures, either increasing use must be made of inorganic insulators or the temperature stability limit of organic materials must be raised. In order that the former may be fully accomplished, a suitable inorganic plastic material must

be developed. Whichever path is chosen, the chemist holds the key to the solution. The engineer can only tell him when he has arrived at the proper solution. Co-operation between engineer and chemist undoubtedly will hasten progress.

References

1. Electricity and Magnetism, J. C. Maxwell. Oxford Press, 1914, volume 1. See also Lectures on Dielectric Theory and Insulation, J. B. Whitehead. McGraw-Hill Book Company, New York, 1927.

2. Some Results of a Kinetic Theory of Insulators, P. Debye. *Physikalische Zeitschrift*, volume 13, pages 97–100, 1912. See also Polar Molecules, P. Debye. Chemical Catalog Company, 1929.

3. The Synthesis Constitution and Uses of Bakelite, L. H. Baekeland. *Industrial and Engineering Chemistry*, volume 1, 1909, page 149.

4. The Modern Theory of Solids, F. Seitz and R. P. Johnson. *Journal of Applied Physics*, volume 8, 1937, pages 84, 186, and 246.

5. Plastics and Electrical Insulation, L. Hartshorn, N. J. L. Megson and E. Rushton. *Journal* of the Institution of Electrical Engineers, London, volume 83, 1938, page 474.

6. Ueber die Dielektrischen Nachwerkungserscheinungen in Festen Nichtleitern, G. M. Voglis. *Zeitschrift für Physik*, volume 109, 1939, pages 59–79.

7. Conductivity in Insulating Oils—II, J. B. Whitehead. AIEE Transactions, volume 50, 1931, page 692.

8. Predetermination of the A-C Characteristics of Dielectrics, J. B Whitehead and A. Banos. AIEE Transactions, volume 51, 1932, page 392.

9. The Dielectric Properties of Insulating Materials, E. J. Murphy and S. O. Morgan. *Bell System Technical Journal*, volume 16, 1937, page 493.

10. Electrophysik der Isolierstoffe, A. Gemant. Julius Springer, 1930, page 103.

11. Dielectric Constant and Loss of Plastics as Related to Their Composition, W. A. Yaeger. *Transactions*, Electrochemical Society, volume 74, 1938, page 113.

12. The Dielectric Properties of Cellulose, W. N. Stoops. *Journal* of American Chemical Society, volume 56, 1934, page 1480.

13. Gaseous Dielectrics, A. Guntherschulze. *Archiv für Elektrotechnik*, volume 31, 1937, page 495.

14. Electricity in Gases, J. S. Townsend. Oxford Clarenden Press, 1915.

15. Ueber die zum Funkenuebergang in Luft, Wasserstoff und Kohlensaeure bei verschiedenen Druckrn erforderliche Potentialdifferenz, F. Paschen. *Annalen der Physik und Chemie*, volume 37, 1889, pages 69–96.

16. Breakdown Studies in Compressed Gases, A. H. Howell. AIEE Transactions, volume 58, 1939 (May section), pages 193–206.

17. Electric Breakdown of Solid and Liquid Insulators, A. Von Hippel. *Journal of Applied Physics*, volume 8, 1937, page 815.

18. The Electrical Breakdown of Rocksalt at High Temperatures, L. Inge and A. Walther. *Technical Physics of the U.S.S.R.*, volume 5, 1938, pages 335–54.

19. The Physical Nature of the Electrical Breakdown of Solid Dielectrics, K. W. Wagner. AIEE Journal, 1922, volume 41, pages 1034–44.

20. Durchschlag von Glas, L. Inge and A. Walther. *Zeitschrift für Physik*, volume 37, 1926, page 292.

21. Durchschlag von Glas in Homogenen aund Nichthomogenen Elektrischen Feldern, L. Inge and A. Walther. *Archiv für Elektrotechnik*, 1928, volume 19, page 257.

22. Fibrous Glass for Electrical Insulation, R. E. Ferris and G. L. Moses. Electrical Engineering, 1938, volume 57, pages 480–3.

23. Impregnated Paper Insulation, J. B. Whitehead. John Wiley and Sons, New York, 1935.

24. Dielectric Stability of Mineral Oil Treated Insulation, F. M. Clark. *Industrial and Engineering Chemistry*, volume 31, 1939, page 327.

25. Temperature Limits Set by Oil and Cellulose Insulation, C. F. Hill. AIEE Transactions, volume 58, 1939 (September section), pages 484–7.

26. The Effect of Various Insulating Materials on Cellulose, H. C. P. Weber. *Industrial and Engineering Chemistry*, volume 31, 1939, pages 804–06.

27. Electrical and Chemical Studies of Oil Oxidation, J. C. Balsbaugh, R. G. Larsen, and J. L. Onclay. *Industrial and Engineering Chemistry*, volume 30, 1938, pages 287–93; 1939, volume 31, pages 318–26.

28. Application of the Grignard Reagent to a Study of Minerals Oils, R. G. Larsen. *Industrial and Engineering Chemistry*, Analytical Edition, volume 10, 1938, page 195.

29. Influence of Gaseous Electric Discharge on Hydrocarbon Oils, L. J. Berberich. *Industrial and Engineering Chemistry*, volume 30, 1938, pages 280–6.

30. Some Problems of Physics in the Application of Dielectrics as Insulators, C. F. Hill. *Journal of Applied Physics*, volume 8, 1937, pages 607–13.

Interior Transportation at the New York World's Fair

FOR temporary buildings, an unprecedented amount of equipment for vertical and horizontal transportation has been provided in the exhibit buildings at the New York World's Fair. Thirteen exhibits have among them 21 elevators and 16 electric stairways. General Motors Building has three elevators and four electric stairways, and the spectator conveyer for the "Futurama" (see article in December 1939 issue). The French Building has five elevators and four electric stairways; the Russian Building, five elevators and two electric stairways; the Theme Building, two electric stairways, one of them the longest in the United States. The American Telephone and Telegraph Building and the Westinghouse Building each have two electric stairways, and the Italian Building has two elevators. Six other buildings—British, Ford Motor, Petroleum Industry, Rumanian, United States Government, and World's Fair Headquarters have one elevator each. The Ford Motor Company also offers direct transportation through part of its exhibit by automobile.

This electric stairway in the Theme Building at the New York World's Fair has a travel of 120 feet and is said to be the longest one in America; it was built by Westinghouse as was the 96-foot one at the right of it

All this interior transportation, with the exception of the Ford cars, represents a total investment of nearly $800,000. The 16 electric stairways alone have a combined maximum one-way capacity of over 90,000 passengers per hour.

Current Progress in Electrical-Insulation Research Reflected at NRC Conference

Recent progress in various phases of electrical insulation research was reflected in the 26 progress reports informally presented at the 12th annual meeting of the Conference on Electrical Insulation of National Research Council, held November 2–4, 1939, at Cambridge, Mass., and reported briefly in the December issue, page 526. One of the four sessions was devoted to chemistry and physics; one to measurements; and two to materials. As was true of last year's sessions, the emphasis was on research in the fundamentals of electrical insulation rather than on applications to practice, although the Conference continued in its unique position of effectively bringing together the active representatives of both the scientific and the "practical" groups interested in the general subject. Brief abstracts reflecting the high lights of the various reports presented are given on this and the following three pages, all based upon abstracts prepared by the respective authors.

Chemistry and Physics

Mineral-Oil Deterioration: Study of Systems and Test—*J. C. Balsbaugh* (*A'23, M'35*), *A. H. Howells* (*A'35*), *A. G. Assaf*. An improved deteriorating system for use in the study of insulating oils has been built having the following features:

1. All-glass system, approximately one liter volume, including a pump for mechanical agitation of the sample and gas dispersion through the sample.
2. Mechanism for automatically maintaining the absolute pressure.
3. Platinum coil for making electrical measurements on the sample during deterioration and without withdrawing test samples from the system.

A series of tests to determine the effect of heat on an oil sample in the presence of nitrogen, the sample being one having a relatively high oxygen content as measured by the Grignard apparatus, the test being carried on with the (*a*) oil alone, (*b*) oil and paper, (*c*) oil and copper, and (*d*) oil, copper, and paper gave the following results (test 335 hours, 110 degrees centigrade; 1,000 hours, 125 degrees centigrade):

1. The power factor of the oil, in the test with oil and paper, decreased slightly with time.
2. The power factor of the oil, in the test with oil by itself, increased slightly with time.
3. The power factor of the oil, in the test with oil, copper, and paper, increased fairly rapidly at first and then at a decreased rate.
4. The power factor of the oil, in the test with oil, copper, and paper, increased rapidly at first to a high value (within 300 hours) and then remained substantially constant.

A relatively large number of light-absorption measurements over the visible range of the spectrum have been made on a series of oils deteriorated by oxidation, both on the oil by itself and on the oil in the presence of copper, at different amounts of oxygen absorbed by the oil. These tests, in general show (volatile products removed during oxidation):

1. The number of absorbing molecules is linearly related to the oxygen absorbed by the oil.
2. The more highly refined oils show a decreased number of absorbing molecules for a given amount of oxygen absorbed by the oil.
3. The presence of copper during the oxidation gives a decreased number of absorbing molecules for a given amount of oxygen absorbed.

Electrical Properties and Densities of Bromo Substituted Aliphatic Acids in Benzene and Dioxane Solutions—*E. J. Van Loon, H. C. Ott, O. M. Arnold*. As part of the investigation of various acids and their derivatives, the dielectric constant at 1,000 kilocycles and density of solutions of α bromo derivatives of propionic, n-butyric, iso-butyric, n-valeric, and n-caproic acids in benzene and dioxane were determined at 25 degrees centigrade. The molar polarizations of the acids in solution were calculated for the different concentrations studied. The lowest concentrations observed were about 0.01 mol fraction of solute. The dipole moments were calculated by neglecting the atomic polarizations. As with unsubstituted acids, the brom-acids are evidently largely associated in benzene, even in dilute solutions, and hence the polarization is much lower than would be shown by single molecules. In dioxane, however, the extrapolated values of polarizations are probably close to the values for single molecules. The power-factor values for the bromo-acid solutions were higher in the dioxane solutions than in the benzene solutions. The higher association of the acids in the benzene solutions probably influences this difference. In the range of frequencies used in these studies (1,000 cycles to 9,000 kilocycles) for several of the acid solutions, no dielectric dispersion was observed within the experimental accuracy of these observations.

The Influence of Field Strength on the Conductance of Electrolytes—*D. J. Mead, R. M. Fuoss*. At low field strengths, and up to fields of the order of one kilovolt per centimeter, electrolytic solutions obey Ohm's law. In solvents of low dielectric constant, however, dissociation is increased by higher field strengths, leading to an initial increase of conductance proportional to field strength. This behavior is called the Wien effect. The linear increase is followed by a subsequent exponential rise of current with field at very high field strengths, and may be one of the mechanisms involved in the high-voltage breakdown of insulating oils due to the enhanced conductance of the (normally weak) electrolytic impurities in them. An experimental study has been made of the Wien effect in solutions of tetrabutylammonium picrate in diphenyl ether, whose dielectric constant is 3.53. At 10^{-3} normal, this solution has a specific conductance of the order of 10^{-10} mho. Conductances at 60 cycles and 50 degrees centigrade were measured at field strengths up to 20 kilovolts per centimeter. After a small quadratic increase, produced by the dissipation of the ionic atmosphere by the field, the conductance increased linearly, by about 1.5 per cent per kilovolt per centimeter. This agrees with the value calculated by Onsager's theory from the temperature and dielectric constant.

Dielectric Properties of the Rutile Crystalline Modification of Titanium Dioxide—*L. J. Berberich* (*A'30, M'36*), *M. E. Bell*. Most materials have dielectric constants in the range 1–10. Notable among the exceptions is rutile, the crystalline modification of titanium dioxide which is stable at high temperatures. Three samples of this material have been investigated in the form of disks pressed from powdered crystals, then sintered. Curves of dielectric constant against frequency show a rise at very low frequencies, probably attributable to interfacial polarization, with a uniformly high value of approximately 100 extending through the highest radio frequencies, falling off only in the infrared region. With increasing temperature the dielectric constant decreases with an average coefficient of 8.2×10^{-4} per degree in the temperature range of 20 to 120 degrees centigrade. Only a very few of the materials investigated so far show this negative coefficient of dielectric constant. The conductivity of rutile is well represented in the high temperature region by a straight line on a semilog plot against the reciprocal of the absolute temperature. A qualitative explanation of the high dielectric constant and negative temperature coefficient can be made in the light of published work on weakly ionic crystals, assuming that the degree of ionic binding varies with the distance between titanium and oxygen atoms, resulting in a large electric moment being formed for a relatively small movement of the mass points.

Phase Potential at the Boundary—Copper–Oil—*A. Gemant*. An effort has been made to determine the degree of resistance of insulating liquids to deterioration by metals, by measurement of the electrochemical potentials at the metal-oil boundary. It is known from theory that the most characteristic feature of electrochemical potential differences is their specific dependence on the concentration in the liquid of the same ions that constitute the metal. The problem, therefore, was to measure the electromotive forces of cells in which the two identical electrodes were immersed in liquids of different metal-ion content. Copper was chosen as a metal, because of its primary importance in electrical machinery. The ion content was produced by dissolving copper oleate in insulating liquids; although solutions of this type are colloidal, they dissociate into ions to a small but finite extent. Data were obtained with cells of the solvent–solution type. According to the thermodynamic equation describing the potentials of such cells, the normal behavior is that the electrode in contact with the more concentrated solution is positive. Data obtained in these

tests with solvents such as benzol, xylene, and kerosene indicate that generally the opposite is the case, the normal effect being reversed. By slightly increasing the electric conductivity of the system, the polarity of the electromotive forces changes to the normal one. Data on concentration cells having a solute ratio of 1 to 10 reveal potentials of the expected order of 20 to 30 millivolts.

Corona and Spark-Over—*W. H. Bennett.* Experiments on the electrical discharge from sharp points show that the surface condition of the point cannot be ignored. In many instances the tip of the discharging point was made sharper by the corona discharge; in others it was dulled. In all cases the tip gradually accumulated a layer of material. Measurements of point discharges in gases other than air have shown that extreme precautions must be taken to eliminate oxygen and other electron attaching gases, in order to obtain discharges free from the pulsating character familiar in air. When such precautions are taken, the discharges are free of pulsations on both negative and positive polarity in hydrogen and helium. The pulsations that occur in carbon monoxide, carbon dioxide, nitrogen, and methane are quite complicated in form in certain ranges, indicating that in these latter gases an explanation different from that of simple electron attachment may be necessary. The pulsations in pure oxygen, ammonia, water vapor in helium, as well as in all unpurified gases are somewhat similar to the pulsations in air.

The Atomphysical Interpretation of Lichtenberg Figures and Their Application to the Study of Gas-Discharge Phenomena—*F. H. Merrill, A. von Hippel (M'37)* The extremely finely detailed drawing in Lichtenberg figures offers an unusually clear record of the early stages of discharge phenomena. A study has been made of the Lichtenberg discharge in nitrogen at pressures ranging from five millimeters of mercury to 30 atmospheres. The discharge progresses in three stages: the primary figure, spark development, and the discharge of negative surface charges (the "back-figure"). Admixture of carbon tetrachloride and experiments in Freon up to six atmospheres show the decisive influence of electronegative components on the development of the phenomena, and reveal the reasons why these new gases are so effective in suppressing corona discharges. Deviations from Paschen's Law, recently observed by several workers, can be interpreted in terms of the photographic evidence gained.

The Electrical Breakdown Strength of Ionic Crystals as a Function of Temperature—*R. C. Buehl (A'36), A. von Hippel (M'37)* It has been generally believed that the breakdown strength of an insulator is constant in the lower temperature range and decreases rapidly at high temperatures, indicating thermal breakdown. The authors have found that, at least in ionic crystals like potassium bromide, a very steep *increase* of breakdown strength with temperature is recorded in the lower range. This new phenomenon in insulators is apparently analogous to the temperature coefficient of the resistance in metals. It allows us to decide between the different theories of breakdown proposed.

Measurements

Effect of Electrode Materials on the Power Factor of a Cable Oil—*A. V. Astin.* At the National Bureau of Standards an investigation has been undertaken to determine the relative effects of various electrode materials on the insulating properties of some liquid dielectrics. Ten different metals have been used as electrodes, and their effect on a low-loss cable oil (Socony *RD* 1035) observed. The power-factor measurements were made in a conjugate Schering bridge with a stress of about 40 volts per millimeter on the oil. Observations made included 60-cycle and 1,000-cycle power factors and one-minute d-c conductivity. Measurements were made at room temperature, 85 degrees centigrade, two intermediate temperatures, at 85 degrees centigrade after the cell had been maintained at this temperature for a period of 18 hours, and then again on cooling to room temperature. Results of the 60-cycle power-factor tests are summarized as follows (values to be multiplied by 10^{-4}):

Electrode Metal	25 C	85 C	After 18 Hr at 85 C	After Cooling to 25 C
Rhodium plate	8	784	921	10
Silver plate	8.5	914	1,046	18
Gold plate	9	1,124	1,681	32
Nickel plate	10.5	910	1,033	17
Chromium plate	13	1,008	1,502	36
Stainless steel	7	830	1,050	13
Monel metal	7	790	1,470	28
Aluminum	16	1,510	1,610	32
Brass	28	2,000	2,592	115
Anodized aluminum	43	2,700	2,600	72

Results of the d-c tests show practically the same order, since there were only slight differences in the d-c and equivalent 60-cycle conductivities.

The Use of Statistical Methods of Analysis in Insulation Research—*L. Egerton, D. A. McLean.* In research studies of impregnated-paper insulation questions are always arising as to the significance to be attached to certain sets of data. This results from the fact that certain properties of the materials can be observed closely enough to be well defined by a limited number of careful measurements while other properties show a decided lack of reproducibility. In order to obtain a good estimate of a property such as life, which varies so widely, an average could be taken of the data obtained on a great many samples. Since life tests are as a rule tedious and expensive, such a solution is seldom practical. This often results in the use of a few observations for estimating the life and necessitates the use of statistical methods of analysis in order to determine with some degree of precision whether or not observed variations in the averages obtained are due to sampling fluctuations or to some assignable cause. However, if prior information regarding its dispersion is available, then statistical methods allow the proper choice of sample size required for a definite desired chance of having an error of not more than a given value in the average. Studies and experiments indicate that statistical methods can be profitably employed for introducing some degree of certainty into a field where the wide fluctuations of data are often confusing.

Decreased Breakdown Strength Caused by Metal and Dielectric Projections in Sphere Gaps—*H. H. Race (A'24, F'39).* Experiments were performed to determine quantitatively the reductions in spark-over voltages caused by metallic and dielectric projections from the surface of a smooth sphere. Studies were made at 60 cycles per second and with $1^1/_2$x40-microsecond impulses with the projections both positive and negative. For most of the tests, 10-inch spheres were used at a fixed spacing of $5^1/_2$ inches. The projections were cut from thin sheet stock with both the upper and lower edges having the same radius as that of the spheres. The vertical height of the projection was varied from $^1/_8$ inch to 2 inches, that is, the ratio of the projection height to gap spacing varied from 2.3 to 36 per cent. The data obtained emphasized the need for care in eliminating metal or dielectric projections when designing high-voltage apparatus using gaseous dielectrics and indicate how extremely difficult it is in practice to realize the ultimate dielectric strength of the gaseous insulation for given electrode spacings.

Further Progress With a New Optical Method for Studying Electrical Discharges—*S. N. Alexander.* This résumé reports the present status of an investigation whose basic features were reviewed at the 1938 conference (*EE, Jan. 1939, p. 42*). The objective has been the development of a new optical method for recording the details of the predischarge stages of electrical breakdown in gases with eventual extension to transparent liquids and solids. The method uses an adaptation of Toepler's "Schlieren" optical arrangement to reveal the discharge channels through the refractive-index gradients produced by the heat associated with the discharge. These variations in refractive index are used as a shutter-like control for a brilliant light source and the ionization paths appear illuminated against a dark background. Sensitivity sufficient to record the early stages of breakdown in gases was sought and the present equipment approaches the right order of magnitude. An estimate of this sensitivity can be had from the fact that a steady temperature difference of 1.5 degrees centigrade between an electrically heated 0.0002-inch wire and still air can be detected by eye and 3 degrees difference has been photographed. A variety of discharge patterns has been photographed to determine the particular suitabilities and limitations of the system. In addition to recording early stages of formation, this new method has shown several patterns of rather unusual form.

Materials

Effect of Service Aging on Several Brands of 24,000-Volt Paper-Insulated Lead-Covered Cable—*D. E. F. Thomas (A'30), C. C. Smith (A'29).* In these studies, eight sections each of four different kinds of 24-kv 350,000-circular-mil sector-type three-conductor cable were placed in service in two tie lines operating in parallel in the same duct bank; continuous records were kept of cable-loading conditions and duct temperatures. Laboratory tests were made on samples of the new cables cut adjacent

to each of the sections placed in service. After approximately three years of service aging, one section of each of the four kinds of cable has been removed for test. Visual examinations of samples cut from each of the four sections disclosed evidence of marked deterioration in only the belted cable impregnated with rosin-free compound. Some deterioration also was found in the shielded cable impregnated with rosin-free compound, but little or none in the shielded and belted cables impregnated with rosin-bearing compound. Measurements of over-all power factor between 20 and 80 degrees centigrade showed an appreciable increase in power factor for the shielded cable impregnated with rosin-free compound and for both of the belted cables at the higher temperatures, but very little change at the lower temperatures. The shielded cable impregnated with rosin-bearing compound showed only a slight increase in over-all power factor. Radial power-factor measurements at 60 degrees centigrade revealed that the rosin-bearing belted cable had a marked increase in power factor throughout the insulation, that the rosin-bearing shielded cable had power-factor increases only near the conductors and shields, and that the rosin-free shielded and belted cables had little or no power-factor increase. Radial hydrophil measurements, made only on the two rosin-free cables showed marked increases near the conductors of the shielded cable, and near the conductors and sheath of the belted cable. Styrenated cross-sectional wafers of all four types of cable showed a slight stretching of the sheaths as a result of service aging. Lead sheath tests disclosed no evidence of sheath deterioration.

Nature of Materials Causing Increase in Power Factor of Liquid Dielectrics Subjected to Corona Discharge—*Joseph Sticher (A'30), J. D. Piper.* These studies were of two types: First, an analytical approach in which the bombarded material itself was studied; second, an approach in which synthetic materials resembling those found in bombarded hydrocarbons were dissolved in oils. In the analytical studies, which were conducted primarily on decalin, it was found that only the polymerization products had a large effect on power factor, which effect seemed to increase as the degree of polymerization increased. This material appeared to be a highly reactive unsaturated hydrocarbon. Of the synthetic hydrocarbons selected to simulate those formed by corona discharge, however, none brought about an increase in power factor of magnitude even approaching that resulting from similar concentrations of the polymeride formed by corona discharge.

The Dependence of the Conductivity of Dry Paper on Temperature and Voltage—*E. J. Murphy, D. A. McLean.* The conductivity of dry paper has been found to increase rapidly with increasing temperature. The relation is not linear when the logarithm of conductivity is plotted against temperature, but becomes linear over long temperature intervals when the logarithm of conductivity is plotted against the reciprocal of the absolute temperature. The conductivity-temperature relation is, therefore, given by the following expression:

$$\gamma = A_1 e^{-B_1/T} + A_2 e^{-B_2/T}$$

where γ is the conductivity, T the absolute temperature, and A_1, A_2, B_1, B_2 are constants. When the logarithm of conductivity is plotted against applied voltage two intersecting straight lines are obtained, indicating that over some ranges of voltage gradient the conductivity increases exponentially with the voltage gradient. The general significance of the results obtained is to indicate that paper behaves more like a material of simple structure than would be expected from the complexity of its structure.

Some Notes on the Application of the Grignard Test to Oil-Impregnated Cable—*R. N. Evans.* By taking advantage of the fact that a Grignard reagent such as n-butyl-magnesium halide yields four times the weight of carbon dioxide per unit volume of hydrocarbon when compared with methyl magnesium halide, a considerable increase in precision may be obtained over some previous methods. In tests made with improved apparatus, the reaction of methyl magnesium iodide in iso-amyl ether at 100 degrees centigrade on type compounds yielded the following results:

1. Ethylbenzoate, benzophenone, n-butanol behaved in a normal manner.

2. Organic acids (benzoic, oxalic, palmitic, acetic, cyclohexane carboxylic, and abietic) gave consistently high results (20 per cent) for the methane evolved and widely scattered yields of reagent added.

3. Peroxides of the benzoyl peroxide type yielded unpredictable results brought about by a deep-seated decomposition of the reagent.

4. Water gave results indicating the lowered reactivity of the second hydrogen in the water molecule.

5. Paper from an atmosphere of 50 per cent humidity indicated that the water on the paper behaved as an alcohol. The excess evolved methane over that equivalent to the independently determined water indicated 1 hydroxyl in 200 was active. A ratio of 1 to 1,000 was obtained for dry paper.

Further experiments at 25 degrees centigrade, brought out that water, acids, and alcohols gave predictable results. It was concluded that a fairly dependable test result representing the alcohol, water, and acid content of an unknown sample may be obtained provided peroxides of certain types were absent. It was further concluded that the measurement of the reagent reacting without evolution of methane would not lend itself to correlation with known groups in the oil sample.

Aging of Cable Insulation Subjected to Elevated Temperatures—a Progress Report—*W. F. Davidson (A'14, F'26).* The tests reported here are part of a much more comprehensive program to investigate the factors determining the maximum economical loading for paper-insulated high-voltage cables. For this particular phase the problems were:

1. To determine the relative stability of representative present-day commercial cables.

2. To determine the relative deterioration in the temperature range 85–100 degrees centigrade, that is, for temperatures slightly above those recognized in current specifications.

3. To investigate the nature of changes in the insulation resulting from temperature.

Cables used were taken from stock lengths of 2/0 single-conductor, 27-kv (0.297-inch wall) lead-covered cable of each of several makes made in 1938. After discarding 15 or 20 feet, test sections each 2 feet long were cut and immediately sealed with cups pressed from lead which were then "burned" to the sheath. About 15 sections of each cable were then put in each of two specially built ovens and an equal number were placed on storeroom shelves to be kept at room temperature. Automatic regulators with program control maintained the test temperature (85 or 100 degrees centigrade) during 21 hours in each day. During the remaining 3 hours, the temperature cycle is adjusted so that the cable is cooled to about 40 degrees centigrade and immediately reheated. The test program provides for removing samples at intervals of from four to eight months over a total period of three years. Electrical tests are first made on the complete sample which is then cut in two—one part is used for tape-by-tape measurements, while the other provides the basis for chemical tests. Data now are available on three sets of samples representing original conditions, after four months, and after eight months, in the 100-degree oven. The electrical measurements showed considerable differences between the various makes of cable. Some tentative explanations have been advanced to account for these differences, but none has received sufficient confirmation to justify presentation here. As yet it is too early to attempt to draw any conclusions as to the relative deterioration under temperatures of 100 degrees as compared with 85 degrees centigrade, nor is it yet possible to offer any very helpful suggestions as to the nature of the changes that have taken place.

Some Impulse-Voltage-Breakdown Tests on Oil-Treated Paper-Insulated Cables—*C. M. Foust (A'22, M'31), J. A. Scott (A'25, M'34).* Impulse-breakdown-voltage tests of oil-treated paper-insulated cables have been made over a range of insulation thickness from 0.187 to 0.6 inch. Testing technique has differed somewhat during the period in which the tests were made (1931–38). Early tests employed a 1x10-microsecond wave, and later tests a 1½x40-microsecond wave. In all tests a positive impulse was applied to the conductor, the lead sheath being grounded. Tests on the thinner insulation were made on samples having 10 feet of lead; all others on 16-foot (lead length) samples using standard porcelain oil-filled terminals of usual design. All cable failures were in the leaded portion. An impulse was applied to the cable of a magnitude well below (approximately 50 per cent) expected breakdown. Successive single waves then were applied each exceeding the previous wave by a constant increment until breakdown occurred. Practically all failures occurred on or near wave crest. Breakdown voltages varied over the following ranges:

Thickness of Insulation (Inches)	Impulse Breakdown Voltage (Crest Kv)
0.187	350–400
0.315	448–610
0.500	630–940
0.600	836–1,115

The tests included several grades or densities of papers, and in general the denser papers gave higher breakdown values.

Breakdown in Impregnated-Paper Insulation—the Influence of Paper Density and of Paper Thickness—*J. B. Whitehead* (*A'00, F'12*). Preliminary results of tests on the influence of paper density on the breakdown and stability of impregnated paper reported last year have been confirmed in the complete work. Four grades of paper of different densities, but from the same wood-pulp stock and all of the same thickness were studied in accelerated life tests. The average duration of the test was about four days. With increasing specific gravity of the paper, the dielectric strength of the impregnated sample shows a noticeable decrease. Within the range of the specific gravity of the paper, the decrease in breakdown voltage is 30.5 per cent and the decrease in life 47 per cent. Careful examination and dissection of the specimens revealed that breakdown almost invariably begins in the narrow channels between two successive spirals of the paper tapes, these channels being filled with oil. Corresponding measurements of dielectric constant of the oil, of the paper, and of the impregnated paper, permit computation of the stresses in these oil channels. It was found that these stresses had approximately the same value for all four grades of paper. Thus the decreasing dielectric strength with increasing paper density is caused by the increased dielectric constant of the impregnated paper, as this increase shifts a greater proportion of the total stress to the oil in the oil channels. The values of the stress in the oil channels immediately preceding failure were in the range of 1,300 to 1,500 volts per mil. The changes observed in the conductivity, dielectric constant, and dielectric loss of impregnated paper with increasing paper density were also found to have values greater than could be accounted for by the simple volumetric differences in the two components, oil and paper. (A paper presenting the results of all these tests is scheduled for publication in the 1940 volume of AIEE TRANSACTIONS.) Since the foregoing work, a series of studies on the influence of the thickness of the paper has been completed. Four thicknesses of paper, all of approximately the same specific gravity and all from the same stock, were studied under the same methods as for the studies on paper density. Nine specimens were prepared from each of the four thicknesses, the total wall thickness of the sample being approximately the same for each specimen. All were tested to breakdown, with capacitance and loss measured at regular intervals. A definite drop was noted in dielectric strength with increasing thickness, and also certain variations in the values of capacitance and power factor. Studies are still under way looking toward an explanation of these variations.

Moisture Absorption—Rubber Insulation—Effect on Electrical Characteristics—*E. W. Davis* (*A'15, F'34*). Brief progress report to indicate the continuing pursuit of the investigation initiated in 1937 by the Insulated Power Cable Engineers Association to determine the effects of water absorption on the electrical-insulating characteristics of various rubber insulating compounds. Round-robin programs involving several hundred tests in the laboratories of three different manufacturers conducted during 1938 and again in 1939 have revealed data that are being studied and analyzed. Check-testing now is being carried out by the other member companies of IPCEA. The compounds tested include both the so-called dry types and submarine types. The immediate object of the study is the standardization of test procedure for determining moisture absorption, with the hope of ultimate classification of the various rubber insulating compounds for the different types of service for which each is best suited.

Electrical Properties in Relation to the Chemical Composition of Glass—*C. W. Parmelee, A. E. Badger*. The most important technical glasses are made from mixtures of soda, lime, and silica. The various physical properties, such as viscosity, surface tension, density, thermal expansion, and index of refraction have been determined for most commercial glasses. Among the electrical properties, recent measurements of power factor at 100 to 5,000 kilocycles have been completed for glasses ranging in composition from 0 to 20 per cent lime, 64 to 78 per cent silica, and balance soda. The electrical resistances for the various compositions also have been measured for various temperatures up to 400 degrees centigrade. The results indicate that high-resistance glasses in this range of composition possess low power factors. The lack of correlation between either of these electrical properties and the equilibrium diagram for these compositions confirms the dissimilarity with regard to other physical properties. From systematic studies such as these, it may be possible to develop glasses possessing properties adapted to specialized commercial uses.

Ionization in Thin Air Gaps—*C. L. Dawes* (*A'12, F'35*), *B. I. Small* (*A'38*). At the last two conferences of this committee, one of the authors presented and analyzed the results of an investigation of the electrical characteristics of ionized gas between parallel planes, one of which was a smooth circular metal electrode and the other a smooth glass disk. The investigation has been continued, and the effect of frequency studied. Tests were made on a three-millimeter gap. The impedance of the glass disk is first measured at different values of voltage, frequency, and temperature. The impedance of the glass and the gap in series is then measured, and the impedance of the glass subtracted to obtain the impedance and hence the electrical characteristics of the gap. The gas was dried air, and these tests were made at 30 degrees centigrade and at a pressure of 780 millimeters of mercury, absolute. Rapid changes were found to occur in the characteristics between 40 and 60 cycles. In this region, both curves have a negative slope, go through a point of inflexion, and then a minimum. The characteristics obtained at 25, 30, and 40 cycles appear to be one family of curves, and those obtained at 50, 60, and 70 cycles another family, differing from the first. Rapid changes in power loss and power factor also occur in the 40–60-cycle region in impregnated-paper cables, when ionization exists. Hence there appears to be a close correlation between the gaps studied in the investigation and the ionization that actually takes place in cables. Preparations now are being made to measure the characteristics of very short gaps.

Some Tests on the Power-Factor Stability of Oil-Impregnated Paper—*W. N. Arnquist, C. E. Trautman*. Power-factor measurements on mineral oils having a viscosity of about 100 Saybolt at 100 degrees Fahrenheit have been made. Capacitors were made up with eight layers of 0.5-mil linen capacitor paper separating aluminum foil electrodes, and impregnated, under vacuum, with the oils to be tested. The 60-cycle 30-degree-centigrade power factor of these capacitors was determined as a function of the time that the specimens were exposed to 800 volts per mil, 60 cycles, at 75 degrees centigrade. The effect of the addition of a small percentage of an antioxidant to some of the oils was studied. Separate tests showed that the compositions were not modified by the addition of this compound. With one exception, all the oils tested were derived from Texas coastal distillates. A very marked improvement in power-factor stability resulted from a moderate sulphuric acid treatment of the distillate, with only a relatively slight change in composition; the antioxidant further stabilized the oil. A Texas oil prepared by intensive solvent extraction giving a Waterman aromatic content of less than one per cent was found to be relatively unstable unless the antioxidant was added. In contrast, a moderately treated paraffin oil, with about two per cent aromatics, showed good power-factor stability. For oils derived from a common source, fairly good correlations between the power-factor stability and properties reflecting the initial oil composition are possible.

Some Electrical Properties of Polyvinyl Chloride-Plasticizer Systems—*J. M. Davies, W. F. Busse*. The plasticated polyvinyl chloride being used by the electrical industry as flameproof, oilproof insulation furnishes an unusually interesting system for the scientific study of dielectrics. In the present work the dielectric properties of a series of unstabilized polyvinyl chloride-tricresyl phosphate compounds were studied over a range of temperatures and a range of frequencies. The dielectric constants of these systems may vary from about three at low temperature to nine or ten at high temperatures. The power-factor maxima occur at about the temperatures expected from the dielectric-constant measurements and are shifted to higher temperature by an increase in frequency. An important and entirely unexpected result of this work was the observation that at the temperature of the power-factor maximum the samples all had about the same mechanical flexibility. The upward trend in the power-factor curve at temperatures above the dipole peak probably is due to ionic conductance. This depends on a great many factors, including purity of the polyvinyl chloride and plasticizer, stability and thermal history of the polyvinyl chloride, and presence of stabilizers. The temperature coefficient of the d-c resistance also depends on these factors. In some cases samples which are relatively inferior at high temperatures may be superior at low temperatures. The addition of a stabilizer reduces the d-c conductivity without affecting the loss due to dipole rotation. However, from the practical standpoint, the best compound may not be the one with the best electrical properties, but rather the one that is best from the standpoint of heat loss, flexibility, and toughness.

News

Of Institute and Related Activities

Varied Program Will Feature AIEE 1940 Winter Convention

TECHNICAL sessions of broad current interest, attractive social events, and a particularly stimulating group of inspection trips have been arranged for the 1940 AIEE winter convention, which will be held in New York, N. Y., January 22–26, with headquarters in the Engineering Societies Building. Papers presenting new treatments of existing theories, new designs of electrical apparatus, and the latest in operating practice will be presented in 18 technical sessions, during the mornings and afternoons. Evenings will be occupied by the presentation of the Edison and Hoover Medals, a popular lecture, and the annual smoker and dinner-dance. In addition, eight unusual inspection trips have been planned, and special entertainment for the women guests has been arranged.

Medal Presentations and Demonstration Lecture

On Wednesday evening, January 24, both the Edison and Hoover Medals will be presented in the engineering auditorium. The Edison Medal was awarded to Philip Torchio "for distinguished contributions to the art of central station engineering and for achievement in the production, distribution, and utilization of electrical energy." As announced in the November 1939 issue, the Hoover Medal "awarded by engineers to a fellow engineer for distinguished public service" will be presented to Gano Dunn.

After the medal presentations a popular lecture on "Atomic Disintegration" will be delivered by Doctor Enrico Fermi, distinguished physicist and Nobel Prize winner in physics for 1938. The lecture will be followed by demonstrations of atomic disintegration by Doctor John R. Dunning of Columbia University.

Presentation of Alfred Noble Prize

Preceding the technical sessions on relays and communication on Tuesday afternoon a general session will be held for the presentation of the Alfred Noble Prize to Claude E. Shannon (A'39) of the Massachusetts Institute of Technology. He was awarded the prize for his paper entitled "A Symbolic Analysis of Relay and Switching Circuits."

Entertainment

The smoker, always a popular event, will be held again at the Hotel Commodore, Tuesday evening, January 23. A special cocktail lounge, reserved for AIEE members and guests, will be open at 5:30 p.m. The dinner is scheduled for 6:30 p.m. and the floor show starts at 8:00. There will be a general get-together in the west ballroom at 9:15 p.m. Seating will be at tables for ten on the main floor and at tables for six and eight in the balcony. All tables are reserved. Reservations should be made early with the AIEE smoker committee, 33 West 39th Street, New York, N. Y. Tickets will be $3.50 each, and must be prepaid.

The Grand Ballroom of the Plaza Hotel will be the setting for the annual dinner-dance and buffet supper to be held Thursday evening, January 25. The Plaza, located at Fifth Avenue and 59th Street, overlooking Central Park, is known for its sparkling atmosphere and excellent cuisine. Spacious lounge rooms adjacent to the ballroom will be reserved for the use of members and their guests during the dance.

Outdoor parking facilities are excellent in the neighborhood and indoor parking will be available at a nominal fee. For those who wish to stay overnight or to dress at the hotel arrangements have been made for a special rate on rooms. For room reservations write or telephone the hotel and mention the AIEE.

George Ellner and his orchestra will again provide music for both the dinner and dance. As in previous years, encores will be limited in order to provide a large number of dances during the evening.

The program for the evening is:

7:00 p.m.	Dinner
9:30 p.m. to 2:00 a.m.	Dancing
Midnight to 2:00 a.m.	Buffet supper

The prices for tickets are:

Dinner and dance	$5.00 per person
Dinner, dance, and buffet supper	6.50 per person
Dance and buffet supper	3.00 per person

Dinner reservation requests should be sent to AIEE dinner-dance committee, 33 West 39th Street, New York, N. Y., checks being made payable to "Special Account, AIEE." All such requests should include names of guests and desired seating arrangements, taking into account the fact that tables seat eight or ten persons. The committee requests that tickets be purchased as early as possible to allow time to work out seating arrangements.

Technical Conferences

Nine conferences have been tentatively arranged, on the following subjects: electric welding, feedback amplifiers, networks, sound, test code for synchronous machines, transportation, increasing use of electronic devices, standards, and definitions. The schedule for these conferences and as much information as is available is given in the technical program.

The conference on sound is sponsored by

Summarized Schedule of Principal Events

(See separate program for women's entertainment)

Monday, January 22

9:00 a.m.	Registration
10:00 a.m.	Electric welding
11:30 a.m.	Conference on electrical welding
10:00 a.m.	Basic sciences and automatic stations Conference on feedback amplifiers
2:00 p.m.	Lightning protection Communication I Conference on networks

Tuesday, January 23

9:30 a.m.	Circuit breakers Communication II Industrial power applications
2:00 p.m.	General session
2:15 p.m.	Relays Conference on sound
6:30 p.m.	Smoker, Commodore Hotel

Wednesday, January 24

9:30 p.m.	Power generation Transportation I Electronics Conference on test code for synchronous machines
2:00 p.m.	Production and application of light Transportation II
3:45 p.m.	Conference on transportation
2:00 p.m.	Conference on increasing use of electronic devices
8:00 p.m.	Edison and Hoover medal presentations; demonstration lecture on "Atomic Disintegration"

Thursday, January 25

9:30 a.m.	Power transmission Instruments and measurements Electrical machinery I
2:00 p.m.	Insulation co-ordination Electrical machinery II Conference on standards Conference on definitions
7:00 p.m.	Dinner-dance, Plaza Hotel

Friday, January 26

All day	Inspection trips

Saturday, January 27

Post-convention trip to Jamestown, Va., and historic Williamsburg to visit the restoration. Further information at the convention registration desk

Technical Program

Monday, January 22

10:00 a.m. Electric Welding

40-11. Power-Factor Correction of Resistance-Welding Machines by Series Capacitors. **L. G. Leroy, Jr.**, General Electric Company

40-55. The Measurement of Spot-Welding Current. **W. F. Hess, R. A. Wyant, and Albert Muller**, Rensselaer Polytechnic Institute

40-56. Resistance of the Spot Weld. **Ladislav Ciganek**, Cechy-Morava

40-57. Power Supply for Resistance-Welding Machines—II, Resistance-Welder Installations. **Subcommittee on Power Supply for Welding Operations, AIEE**

11:30 a.m. Conference on Electric Welding

40-58-ACO.* Power Supply for Resistance-Welding Machines—I, Guide to Good Electrical Performance of Resistance-Welding Machines. **Subcommittee on Power Supply for Welding Operations, AIEE**

10:00 a.m. Basic Sciences and Automatic Stations

40-5. Analysis of Transient Voltages in Networks. **P. L. Bellaschi and A. J. Palermo**, Westinghouse Electric and Manufacturing Company

40-2. Transient Analysis of Symmetrical Networks by the Method of Symmetrical Components. **L. A. Pipes**, Harvard University

40-21. Generalized Bridge Network for Dielectric Measurements. **J. C. Balsbaugh, A. H. Howell, and J. V. Dotson**, Massachusetts Institute of Technology

40-26. Synchronizing Transients and Synchronizers for Large Machines. **R. D. Evans, F. H. Gulliksen, and C. B. Myhre**, Westinghouse Electric and Manufacturing Company

10:00 a.m. Conference on Feedback Amplifiers

2:00 p.m. Lightning Protection

40-22. Lightning Protection of Wood-Pole Lines. **H. K. Sels and A. W. Gothberg**, Public Service Electric and Gas Company

40-59. Lightning Currents in Arresters at Stations. **I. W. Gross**, American Gas and Electric Company, **and W. A. McMorris**, General Electric Company

40-60. Lightning and Lightning Protection on Distribution Systems. **R. C. Bergvall and Edward Beck**, Westinghouse Electric and Manufacturing Company

40-61. Enclosed Spark Gaps. **W. E. Berkey**, Westinghouse Electric and Manufacturing Company

40-62. Station-Type Lightning-Arrester Performance Characteristics. **Lightning Arrester Subcommittee, Committee on Protective Devices, AIEE**

2:00 p.m. Communication I: Use of Radio for Airplane Navigation and Weather Forecasting

40-43. The Development of the Civil Aeronautics Authority Instrument Landing System at Indianapolis. **W. E. Jackson**, Civil Aeronautics Authority, **Andrew Alford and P. F. Byrne**, International Telephone Development Company, **and H. B. Fischer**, Bell Telephone Laboratories, Inc.

* ACO: Advance copies only available; not intended for publication in Transactions.

Photo-offset copies of authors' manuscripts, except addresses, may be obtained in advance of the convention by writing to the AIEE Order Department, 33 West 39th Street, New York, N. Y. Only numbered papers will be available in advance copy form. If ordered by mail, price 10¢ per copy; if purchased at Institute headquarters or at the convention, 5¢ per copy. Mail orders (particularly from out-of-town members) are advisable, inasmuch as an adequate supply of each paper at the meeting cannot be assured. Coupon books in $1.00 and $5.00 denominations are available for those who wish to avoid remittance by check or otherwise. Most of the papers ultimately will be published in Electrical Engineering or the Transactions.

40-44. The CAA-MIT Instrument Landing System. **E. L. Bowles, W. L. Barrow, W. M. Hall, F. D. Lewis, and D. E. Kerr**, Massachusetts Institute of Technology

40-45. Ultrahigh-Frequency Loop Antennas. **Andrew Alford and A. G. Kandoian**, International Telephone Development Company

40-47. Upper-Air Weather Soundings by Radio. **Harry Diamond, W. S. Hinman, Jr., F. W. Dunmore, and E. G. Lapham**, National Bureau of Standards

2:00 p.m. Conference on Networks

Tuesday, January 23

9:30 a.m. Circuit Breakers

40-19. The Cross-Air-Blast Circuit Breaker. **D. C. Prince and W. K. Rankin**, General Electric Company, **and J. A. Henley**, Metropolitan Vickers Company Ltd.

40-63. Design and Construction of High-Capacity Air-Blast Circuit Breakers. **H. E. Strang and A. C. Boisseau**, General Electric Company

40-64. A New 15-Kv Pneumatic Circuit Interrupter. **L. R. Ludwig, H. L. Rawlins, and B. P. Baker**, Westinghouse Electric and Manufacturing Company.

40-65. Magnetic Orion Air Breaker for 2,500–5,000 Volts. **L. R. Ludwig and R. H. Nau**, Westinghouse Electric and Manufacturing Company

40-66. Circuit Interruption by Air Blast. **W. S. Edsall and S. R. Stubbs**, Allis-Chalmers Manufacturing Company

9:30 a.m. Communication II

40-49. Co-ordination of Power and Communication Circuits for Low-Frequency Induction. **J. O'R. Coleman**, Edison Electric Institute, **and H. M. Trueblood**, Bell Telephone Laboratories, Inc.

40-50. Control of Inductive Interference to Telegraph Systems. **J. W. Milnor**, Western Union Telegraph Company

40-51. High-Speed Voice-Frequency Carrier Telegraph System. **F. B. Bramhall**, The Western Union Telegraph Company

40-20. Compressed Powdered Molybdenum Permalloy for High-Quality Inductance Coils. **V. E. Legg and F. J. Given**, Bell Telephone Laboratories, Inc.

40-52. Calculation and Design of Resistance-Coupled Amplifiers Using Pentode Tubes. **F. E. Terman, W. R. Hewlett, C. W. Palmer and Wen-Yuan Pan**, Stanford University

40-53. Contact Phenomena in Telephone Switching Circuits. **A. M. Curtis**, Bell Telephone Laboratories, Inc.

9:30 a.m. Industrial Power Applications

40-7. Dynamoelectric Amplifier for Power Control. **E. F. W. Alexanderson, M. A. Edwards, and K. K. Bowman**, General Electric Company

40-10. The Design Characteristics of Amplidyne Generators. **Alec Fisher**, General Electric Company

40-23. Industrial Applications of Amplidyne Generators. **D. R. Shoults, M. A. Edwards, and F. E. Crever**, General Electric Company

40-54. Characteristics and Power Requirements of Spinning Frames, II. **E. A. Untersee**, General Electric Company

2:00 p.m. General Session

Presentation of Alfred Noble Prize to Claude E. Shannon, Massachusetts Institute of Technology

2:15 p.m. Relays

40-67. Over-Current Performance of Bushing-Type Current Transformers. **C. A. Woods, Jr., and S. A. Bottonari**, Westinghouse Electric and Manufacturing Company

40-68. A Proposed Method for the Determination of Current-Transformer Errors. **G. Camilli and R. L. Ten Broeck**, General Electric Company

40-69. Analysis of Bushing-Current-Transformer Performance. **J. P. Gebelein**, Consumers Power Company, **and J. A. Elzi**, Commonwealth and Southern Corporation

40-70. Transient Characteristics of Current Transformers. **A. T. Sinks**, General Electric Company

40-71. Current Transformers and Relays for High-Speed Differential Protection, With Particular Reference to Offset Transient Currents. **E. C. Wentz and W. K. Sonnemann**, Westinghouse Electric and Manufacturing Company

2:15 p.m. Conference on Sound

CP.† New Information on Sound Levels Existing in Various Locations. **D. F. Seacord**, Bell Telephone Laboratories, Inc.

CP.† Progress in Sound-Level Meter Standards—Calibration Methods and Tolerances. **J. M. Barstow**, Bell Telephone Laboratories, Inc.

CP.† Progress in Vibration Measurements—Shall a Test Code on This Subject Be Developed? **C. D. Greentree**, General Electric Company

CP.† Experiences in Sound Measurements. **E. J. Abbott**, Physicists Research Company

40-13. Harmonic Theory of Noise in Induction Motors. **W. J. Morrill** General Electric Company

Wednesday, January 24

9:30 a.m. Power Generation

40-30. The Design and Operation of a Metropolitan Electrical System From the Viewpoint of Possible Major Shutdowns. **S. M. Dean**, The Detroit Edison Company

† CP: Conference paper; no advance copies available; not intended for publication in Transactions.

Technical Program (Continued)

40-31. Restoration of Service From Large Metropolitan System After Complete Shutdown. **H. A. Dryar** and **Raymond Bailey**, Philadelphia Electric Company

40-32. Restoration of Service on a Metropolitan Power System. **W. C. Bryson** and **A. P. Hayward**, Duquesne Light Company

40-33. Provisions for Re-energizing the Electric System of the Consolidated Edison Company of New York, Inc. **G. R. Milne** and **H. C. Otten**, Consolidated Edison Company of New York, Inc.

40-6. Report on Power Generation. **AIEE Committee on Power Generation, 1938-1939** (*EE, Jan. '40 p. 12-22.*)

9:30 a.m. Transportation I

40-4. Railway Power Supply. **Philip Torchio**, retired, Consolidated Edison Company of New York, Inc.

40-27. Power Supply for Railroad Electrification and Fundamentals of Power Contracts. **E. R. Hill**, Gibbs and Hill, Inc.

40-14. The Application of Traction Motors. **F. E. Wynne** and **G. M. Woods**, Westinghouse Electric and Manufacturing Company

40-16. Network Coupling by Means of Static Electronic Frequency Changers. **O. K. Marti**, Allis-Chalmers Manufacturing Company

9:30 a.m. Electronics

40-74. Excitron Mercury-Arc Rectifier. **O. K. Marti**, Allis-Chalmers Manufacturing Company

40-18. A New Electronic Multiplier for Power Frequencies. **W. P. Overbeck**, Massachusetts Institute of Technology

40-72. Condensation of Mercury in Mercury-Arc Tubes. **Joseph Slepian** and **W. M. Brubaker**, Westinghouse Electric and Manufacturing Company

40-73. Phase Occurrence of Arc-Backs in High-Current Mercury-Arc Rectifiers. **W. E. Pakala** and **W. B. Batten**, Westinghouse Electric and Manufacturing Company

40-75. A New Postgraduate Course in Industry in High-Frequency Engineering. **A. R. Stevenson, Jr.**, and **Simon Ramo**, General Electric Company

9:30 a.m. Conference on Test Code for Synchronous Machines

2:00 p.m. Production and Application of Light

40-1. Report on Progress in the Production and Application of Light—Demonstration lecture. **A. L. Powell**, General Electric Company (*EE, Dec. '39, p. 497-508*)

Address: Lighting the New York World's Fair. **R. C. Engelken**, New York World's Fair Corporation

Address: Lighting of the North Beach Airport. **Major Haslett**, aviation consultant at the New York Municipal Airport

2:00 p.m. Transportation II

40-15. Unsolved Problems of Electrical Engineering in the Field of Transportation. **J. A. Noertker**, Cincinnati Street Railway Company

40-28. Electric Braking for Railroad and Urban Transit Equipment. **F. H. Craton** and **F. M. Turner**, General Electric Company

40-24. Electric Power for Airplanes. **W. J. Clardy**, Westinghouse Electric and Manufacturing Company

3:45 p.m. Conference on Transportation

40-29-ACO.* Trends in Railroad Motive Power. **Sidney Withington**, New York, New Haven, and Hartford Railroad Company

2:00 p.m. Conference on Increasing the Use of Electronic Devices

Thursday, January 25

9:30 a.m. Power Transmission

40-17. Engineering Features of the 230-Kv Boulder-Chino Transmission Line of the Southern California Edison Company, Ltd. **A. A. Kroneberg**, Southern California Edison Company, Ltd., and **E. M. Hunter**, General Electric Company

40-25. What Wood May Add to Primary Insulation for Withstanding Lightning. **J. T. Lusignan** and **C. J. Miller**, Ohio Brass Company

40-9. Surge Characteristics of a Buried Bare Wire. **E. D. Sunde**, Bell Telephone Laboratories, Inc.

40-8. Some Impulse-Voltage Breakdown Tests on Oil-Treated Paper-Insulated Cables. **C. M. Foust** and **J. A. Scott**, General Electric Company

40-34. Impulse Strength of Cable Insulation. **E. W. Davis** and **W. N. Eddy**, Simplex Wire and Cable Company

9:30 a.m. Instruments and Measurements

40-39. The Speedomax Power-Level Recorder. **W. R. Clark**, Leeds and Northrup Company

40-40. The Accuracy of Watt-Hour Meters on Intermittent Loads. **M. A. Faucett, C. A. Keener**, and **M. S. Helm**, University of Illinois

40-41. A Primary Rotating Standard for the Measurement of Kilowatt Hours. **J. H. Goss** and **A. Hansen, Jr.**, General Electric Company

40-42. Watt-Hour-Meter Performance With Power Rectifiers. **C. T. Weller, H. E. Trekell**, and **F. O. Stebbins**, General Electric Company

40-48. The Vector-Response Indicator. **B. D. Loughlin**, Hazeltine Service Corporation

9:30 a.m. Electrical Machinery I

40-77. Water Solution in High-Voltage Dielectric Liquids. **F. M. Clark**, General Electric Company

40-78. Determination of Short-Circuit Torques in Turbine Generators by Test. **E. C. Whitney** and **H. E. Criner**, Westinghouse Electric and Manufacturing Company

2:00 p.m. Insulation Co-ordination

40-83. Basic Impulse Insulation Levels. **Philip Sporn**, American Gas and Electric Company, and **C. A. Powel**, Westinghouse Electric and Manufacturing Company

40-35. The Co-ordination of Electrical Equipment With Basic Insulation Levels. **J. H Foote** and **J. R. North**, The Commonwealth and Southern Corporation

40-36. Rationalization of System Insulation III, Margins Between Basic Insulation Levels and Protectable Levels. **Philip Sporn** and **I. W. Gross**, American Gas and Electric Company

40-37. Proposed Standards for Outdoor Bushings. **AIEE Joint Committee on Bushings.**

40-38. Recommendations for High-Voltage Testing. **Subcommittee on Correlation of Laboratory Data of EEI-NEMA Joint Committee on Insulation Co-ordination**

2:00 p.m. Electrical Machinery II

40-79. Heating of a D-C Armature. **C. J. Fechheimer**, Milwaukee School of Engineering

40-80. Theory of Hysteresis Motor Torque. **B. R. Teare, Jr.**, Carnegie Institute of Technology

40-12. Induction Motor Characteristics at High Slip. **T. H. Morgan**, Worcester Polytechnic Institute, **W. E. Brown**, Colt's Patent Fire Arms Manufacturing Company, and **A J. Schumer**, Fischbach and Moore, Inc.

40-3. Starting Performance of Salient-Pole Synchronous Motors. **M. M. Liwschitz**, Westinghouse Electric and Manufacturing Company

40-46. Electric Couplings. **M. R. Lory, L. A. Kilgore**, and **R. A. Baudry**, Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference on Standards

2:00 p.m. Conference on Definitions

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the subcommittee on sound of the standards committee to review recent developments in the field of sound and vibration measurement. Speakers will present new information on sound levels existing in various locations; on progress in sound level meter standards, particularly calibration methods and tolerances; and on recent experiences in sound measurement in various fields. It is also planned to renew discussion of vibration measurements, which are more and more coming to be made by means of sound-level meters using suitable vibration pick-up devices.

This annual conference serves as a means of bringing forward new proposals for sound measurement or noise reduction, and acquainting Institute members with progress in the sound-measurement art.

Inspection Trips

The inspection trips committee is arranging a program of inspection trips throughout the week and on Friday, which is to be devoted entirely to this activity. The following are among those scheduled:

1. Train-dispatching operations and inspection of latest car-lighting applications at Grand Central Terminal.

2. Inspection of NBC television broadcasting studios at Radio City, transmission apparatus at the Empire State Building, and television receivers.

3. Trip to General Cable Corporation plant at Bayonne, N. J.

4. Trip to Westinghouse Lamp Works, Meter Works, and Elevator Factories; luncheon at the Lamp Works.

5. Inspection of Associated Press building, equipment and operations.

6. American Telephone and Telegraph Company traffic-control demonstration. Attendance limited to members only.

7. Inspection of New York Telephone Company cross-bar central office.

8. Trip to New York Municipal Airport, North Beach; sightseeing flight over New York City in modern transport planes; and demonstration of field lighting.

In addition to the trips, tickets to several broadcasts will be available to members attending the convention. Arrangements may also be made for a post-convention trip

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to Jamestown and historic Williamsburg, Va., to see the restoration. Further details will be available at the convention registration desk. Among the preceding list of inspection trips the following are believed to be of more than usual interest:

Traffic Control Demonstration. In the New York headquarters building of the American Telephone and Telegraph Company's long lines department is a group of men and women known as the traffic control bureau. There are similar groups in Cleveland and Chicago. Together they direct and co-ordinate the movement of telephone traffic over more than two and a half million miles of long-distance lines.

Every day—almost every hour—brings sudden sharp variations from the average flow of telephone calls. Hurricanes and floods, conventions and World Series games—these and other events make necessary quick and often extensive rearrangements of long-distance facilities. Calls must be detoured around line breaks. Additional circuits are urgently required. Other emergency adjustments may have to be made.

To illustrate the traffic control bureau's important part in keeping calls moving under such circumstances, the work of the bureau has been dramatized for demonstration purposes. In a fast-moving 50-minute presentation, employees in the New York bureau re-enact an actual case involving a major cable break. The action starts with the first report of trouble. Telephone and teletypewriter flash information between the bureau and distant offices. Advice, reports, suggestions speed from New York to key points in a dozen directions. Discussions take place over conference hook-ups. A growing number of circuits are arranged to by-pass the break. Finally the display board, which records the minute-by-minute condition of each circuit, resumes its normal appearance. Service is going along at its usual pace.

On January 26 the demonstration will be given twice for members of the Institute, at 10:00 and 11:15 a.m., in the long-distance building, 32 Sixth Avenue. Admission will be by ticket only, and the number of tickets is limited. Application for reservations should be made at the inspection trips desk early during the convention.

NBC Television Studio Facilities at Radio City. Members in groups of approximately 20 will be given an opportunity to inspect the NBC building, where they will see a modern television studio with latest lighting equipment, cameras and production facilities, control room and control equipment used in the production of live-talent performances.

Inspection will include the projection studio which is equipped to transmit both 35- and 16-millimeter motion pictures. Installed in this pioneer television production plant are the very latest types of RCA television equipment developed in actual practice over a period of three years of practical operation. In the live-talent studio, the camera will be in operation, so that members who take this trip will be able to see their companions appear on the monitor through the television system.

Those interested in seeing the NBC sound and vision transmitters will be afforded an opportunity to go to the Empire State Building and there inspect these modern ultrashort-wave television transmitters.

Tickets, assigning a specific time for the arrival of each group at Radio City, will be distributed to members requesting them.

New York Municipal Airport. A series of five scenic flights that will permit members attending the convention to view New York City from the air will be operated from New York's new $50,000,000 La-Guardia Field on Friday, January 26. Arrangements have been completed with United Air Lines enabling 105 people to make 75-mile trips around the five boroughs of the skyscraper city in 21-passenger transports.

Accompanying the air trip will be a tour of the huge landplane administration building and the three hangars now being shared by four lines, American, United, TWA, and Canadian Colonial. These other hangars are nearing completion and a fourth is projected. Similar in size, each will be larger than Madison Square Garden.

One of the finest air terminals in the world, LaGuardia Field has combined facilities within its 558-acre space for both a landplane and seaplane base and ultra-modern facilities for passenger handling. The administration building, more than four stories in height, has separate levels for incoming and outbound passengers and promenade decks for sightseers. In the building are three restaurants, a coffee shop, barber shop, newsstand, and flower shop. Above the passenger levels are operating offices for some of the airlines—nerve centers for plane control via radio-telephone and teletype. The highest part of the building is the glass-enclosed control tower from which takeoffs, landings, and approaches are guided. On this tower, which will be shown on the guided tour, is a revolving beacon said to be the most powerful in the world. The lighting of the airport is to be described at one of the sessions by Major Haslett, aviation consultant at the airport.

Some Winter-Convention Attractions

(See Facing Page)

1, 2. An inspection trip to the newly opened New York Municipal Airport will include a 75-mile air trip for a limited number, a tour of the landplane administration building and three hangars (1) and an inspection of the glass enclosed control tower atop the administration building (2)

3, 4, 5. Radio City, a perennial favorite among winter conventioners since the huge Music Hall theater was opened there several years ago, now has its tallest structure—the 70-story RCA building—floodlighted at night (5). In addition to the usual attractions, there will be an inspection trip to the television studios of the National Broadcasting Company, which will include a tour of the NBC building, a modern television studio, and control room (4). There will also be an opportunity to see the television transmitters and antenna (3) at the pinnacle of the Empire State Building

6, 7. Inspections of communication facilities will include: traffic-control office of the American Telephone and Telegraph Company (6) where the work of the traffic-control bureau will be demonstrated; and a cross-bar central office (7)

8. The gleaming towers of New York's financial district from the air

Photos courtesy of: (1) Transcontinental and Western Air, Inc.—William T. Hall; (2) *Aviation*; (3, 4) National Broadcasting Company; (5) Westinghouse; (6, 7) American Telephone and Telegraph Company; (8) American Airlines

Women's Program

In addition to the medal presentations on Wednesday evening and the dinner-dance on Thursday evening, women guests will be interested in the following events arranged by the women's entertainment committee, under the chairmanship of Mrs. G. S. Rose.

Monday, January 22

9:00 a.m.–4:00 p.m. Registration

Tuesday, January 23

10:00 a.m. Bus trip around both upper and lower New York, returning to Engineering Societies' Building at 1:30 p.m. Special coaches with glass roof and lecturer. Special rate $1.50. Please register on Monday. Men welcome.

3:00 p.m. Radio City. Tea in the Rainbow Room and a trip to the Tower, courtesy of Westinghouse

7:30 p.m. "Consolidated Edison" broadcast

9:00 p.m. "We the People" broadcast

Wednesday, January 24

Annual luncheon and bridge, Ambassador Hotel

Thursday, January 25

Various trips to museums, art galleries, and other points of interest.

Hotels and Registration

Reservations for hotel accommodations should be made by writing directly to the hotel of your preference. Members east of the Mississippi who receive the mailed announcement of the winter convention should fill in and post promptly the mail registration card. This will permit badges to be made ready in advance of arrival and avoid congestion at the registration desk. There will be a registration fee of $2.00 for non-members, except Enrolled Students of the Institute and the immediate families of members.

Winter Convention Committee

The personnel of the 1940 winter convention committee is as follows: A. F. Dixon, chairman; J. W. Barker, T. F. Barton, G. E. Dean, E. E. Dorting, L. C. Miller, A. G. Oehler, J. H. Pilkington, C. S. Purnell, George Sutherland, and W. W. Truran. The chairmen of the sub-committees completing the arrangements are: T. S. Bacon, dinner-dance; D. W. Taylor, smoker; R. F. Brower, inspection trips; and Mrs. G. S. Rose, women's entertainment.

Committee to Nominate AIEE Officers for 1940–41

In accordance with the Institute's by-laws, the national nominating committee of the AIEE will meet during the winter convention to be held in New York, N. Y., January 22–26, 1940, for the purpose of nominating national officers to be voted upon by the membership in the spring of 1940. Members of this year's national nominating committee are as follows:

Representing the Board of Directors

C. R. Beardsley, Consolidated Edison Company of New York, Inc., New York, N. Y.

Chester L. Dawes, Harvard University, Cambridge, Mass.

Mark Eldredge, Memphis Light, Gas, and Water Division, Memphis, Tenn.

A. H. Lovell, University of Michigan, Ann Arbor.

C. A. Powel, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Representing the Ten Geographical Districts

1. W. B. Hall, Rhode Island State College, Kingston, R. I.

2. I. Melville Stein, Leeds and Northrup Company, Philadelphia, Pa.

3. George Sutherland, Consolidated Edison Company of New York, Inc., New York, N. Y.

4. J. Coleman Jones, Florida Power and Light Company, Miami.

5. T. G. LeClair, Commonwealth Edison Company, Chicago, Ill.

6. A. L. Turner, Northwestern Bell Telephone Company, Omaha, Nebr.

7. A. S. Langsdorf, Washington University, St. Louis, Mo.

8. Fred Garrison, General Electric Company, Los Angeles, Calif.

9. Henry L. Vincent, Westinghouse Electric Supply Company, Spokane, Wash.

10. J. M. Thomson, Ferranti Electric, Ltd., Toronto, Ont.

Alternates for board representatives:

T. F. Barton, General Electric Company, New York, N. Y.

H. S. Osborne, American Telephone and Telegraph Company, New York, N. Y.

Provisions of the AIEE constitution and bylaws relating to nominations were given in ELECTRICAL ENGINEERING for November 1939, page 484. President Farmer's message, on page 449 of the same issue, outlined the election machinery, and made suggestions for broader participation in nominations.

In addition to those to be designated by the national nominating committee, nominations also may be made independently, by petition of 25 or more members sent to the national secretary at Institute headquarters, not later than March 25, to be placed before the nominating committee for inclusion in the ballot of such candidates as are eligible. Petitions for the nomination of vice-president may be signed only by members within the District concerned.

Future AIEE Meetings

Winter Convention
New York, N. Y., January 22–26, 1940

Summer Convention
Swampscott, Mass., June 24–28, 1940

Pacific Coast Convention
Los Angeles, Calif., August 26–30, 1940

Charles LeGeyt Fortescue Fellowship Established

A fellowship for graduate study, sponsored by the AIEE, has been established as a memorial to Charles LeGeyt Fortescue (A'03, F'21) in recognition of his valuable contributions to the electric-power industry. A trust fund of $25,000 has been set up for this purpose by the Westinghouse Electric and Manufacturing Company, with which Doctor Fortescue was associated throughout his professional career. The income, which will be administered by a committee of the AIEE, will be used to provide fellowships of $500 or more to candidates selected annually by the committee.

Holders of the fellowships will be expected to pursue their studies at accredited engineering schools and to engage in research problems meeting the approval of the committee. Any student of electrical engineering who has received a bachelor's degree before the fellowship becomes active is eligible for the awards. Candidates must make application in due form to the secretary of the fellowship committee before February 15. Application forms are available at accredited colleges or may be obtained from the secretary at AIEE headquarters, 33 West 39th Street, New York, N. Y. Awards will be made not later than April 1. Fellowships will not be awarded to those who hold or may hold other fellowships that carry stipends greater than the tuition of the institution at which graduate study will be undertaken.

Charles LeGeyt Fortescue, in whose honor the awards have been founded, was born November 7, 1876, at York Factory, Manitoba, Can. He was the first student graduated as an electrical engineer from Queen's University, which later awarded him the degree of doctor of laws. Following graduation in 1898 he joined the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., where he spent his entire professional life. He died December 4, 1936. A prolific inventor, holder of some 185 patents, he is probably best known for his system of symmetrical coordinates used in the solution of unbalanced polyphase circuits, for which he was awarded the Elliott Cresson Medal of the Franklin Institute. His analysis of the fundamentals of transmission circuit stability and his theories of lightning behavior and derived principles of lightning protection are also conspicuous as lasting achievements, while among his contributions to the problems of his time are his rationalization of transformer design, studies of high-voltage measurements culminating in the adoption of the standard sphere spark gap, and fundamental work on porcelain insulator surface shapes involving the "faradoid" principle.

1939 Noble Prize Awarded to Institute Member

The Alfred Noble prize for 1939 has been awarded to C. E. Shannon (A'39) assistant in mathematics, Massachusetts Institute of Technology, Cambridge, for his paper "A Symbolic Analysis of Relay and Switching Circuits." The paper, an abstract of a thesis for master's degree, prepared while the author was a research assistant at MIT and a student member of the Institute, was presented at the AIEE summer convention, Washington, D. C., June 20–24, 1938, and published in the 1938 TRANSACTIONS, pages 713–23. A biographical sketch of Mr. Shannon appears in the "Personal Items" section of this issue, page 48. Formal presentation of the award will be made at the AIEE winter convention to be held in New York, N. Y., January 22–26.

Instituted in 1929 in honor of Alfred Noble, past-president of the American Society of Civil Engineers and of the Western Society of Engineers, the prize has been presented seven times, the first award having been made in 1931. It consists of a $500 cash award and a certificate. Mr. Shannon is the fourth AIEE member to receive it, the others being F. M. Starr (A'30, M'37) 1932; Abe Tilles (A'30, M'36) 1936; and G. M. L. Sommerman (A'31, M'37) 1937. The recipient is selected by a committee of five, representing the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, the AIEE, and the Western Society of Engineers. The award is made to a member of one of those societies for a technical paper of particular merit accepted by the publication committee of any of the societies for publication in whole or in abstract in any of their respective publications, provided that the author is not over 30 years of age at the time the paper is accepted in practically its final form. The award is now made for papers presented during the 12 months preceding June 1 of each year.

AIEE Executive Committee Meets at Headquarters

A meeting of the executive committee of the AIEE was held at Institute headquarters, New York, N. Y., on December 11, 1939, in place of the regular meeting of the board of directors.

Present: President F. Malcolm Farmer, chairman, W. H. Harrison, K. B. McEachron, H. S. Osborne, John C. Parker, W. I. Slichter, members of the committee; National Secretary H. H. Henline.

Executive committee action on applications as of November 21, 1939, was reported and approved, as follows: 3 applicants transferred to the grade of Fellow; 14 applicants transferred and 4 elected to the grade of Member; 23 applicants elected to the grade of Associate; 572 Students enrolled.

A report was presented and approved of actions taken by the board of examiners

at its meeting held on November 16, 1939.

Disbursements in November, amounting to $21,787.79, were reported by the chairman of the finance committee and approved.

The executive committee granted a request of the technical program committee for an extension of the authority already given it to hold a joint session with Section M (Engineering) of the American Association for the Advancement of Science at one of the Institute's conventions to include authority to hold a joint session with American Engineering Council.

Upon recommendation of the Sections committee, authorization was given for the organization of a Charleston, W. Va., Section of the Institute.

Report was made of the completion of the duties of the special committee appointed to collaborate with the Westinghouse Electric and Manufacturing Company in working out the details for the establishment of a graduate fellowship as a memorial to the late Charles LeGeyt Fortescue, to be known as the Charles LeGeyt Fortescue Fellowship, the funds for the purpose being donated by the Westinghouse Company and the fellowships to be awarded by a committee of the AIEE. The trust agreement between the Westinghouse company and the Institute had been signed, and bylaws of the AIEE committee that will award the fellowships had been adopted. The special committee, therefore, was discharged, with an expression of appreciation of its services.

Upon request of the committee on engineering schools of the Engineers' Council for Professional Development, approval was given for the appointment of the following AIEE representatives on delegatory committees of ECPD, engaged in the ECPD program for accrediting engineering schools: T. H. Morgan and H. B. Richmond, Region I; C. H. Willis, Region II; A. C. Lanier, Region V; F. O. McMillan, Region VII.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Eta Kappa Nu Awards Announced for 1939

L. A. Meacham, Bell Telephone Laboratories, Inc., New York, N. Y., has been named by Eta Kappa Nu, honorary electrical engineering society, to receive its Recognition of Outstanding Young Electrical Engineers for 1939. Mr. Meacham was chosen from over 40 candidates nominated from every section of the country by heads of college electrical-engineering departments, personnel directors in the electrical industry, and Sections of the AIEE. He is the fourth man to receive this honor. Two honorable-mention awards have also been announced for 1939, to be given to C. K. Gieringer (A'35), chief engineer, Liebel - Flarsheim Company, Cincinnati, Ohio, and J. E. Hobson (A'36), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Biographical sketches of the honorable-mention winners appear in the "Personal Items" section of this issue, page 48.

The awards were made by a committee of prominent engineers: Chairman H. S. Rogers, president, Polytechnic Institute of Brooklyn; Morris Buck, engineering editor, *Transit Journal*, McGraw-Hill Publishing Company; A. M. Dudley (A'08, F'13,) Westinghouse Electric and Manufacturing Company; F. M. Farmer (A'02, F'13, president) vice-president and chief engineer, Electrical Testing Laboratories; W. H. Harrison (A'20, F'31, past president), vice-president and chief engineer, American Telephone and Telegraph Company; and G. P. Sawyer, Cerro de Pasco Copper Corporation.

Inaugurated in 1936 to recognize "meritorious service in the interests of their fellowmen," the Eta Kappa Nu award, is given to electrical engineers graduated not more than 10 years, and less than 35 years of age. Careful consideration is given to civic, social and cultural activities, as well as to technical achievements, in making the final choices.

The annual award dinner will be held in New York on Monday evening, January 22, the first day of the AIEE winter convention, in order to afford an opportunity for out-of-town Institute members to attend. Mr. Meacham will be presented with a small replica of the large bronze bowl which stands in the trophy case at Institute headquarters and on which his name will be engraved.

Southern District Executive Committe Meets

The annual meeting of the executive committee of AIEE District 4 was held at Atlanta, Ga., November 25, 1939. Those present were:

F. R. Maxwell, Jr., vice-president, District 4
A. S. Hoefflin, secretary, District 4
S. W. Anderson, vice-chairman, District 4, national membership committee
L. L. Patterson, chairman, District committee on student activities
W. W. Hill, chairman; T. H. Mawson, secretary; Alabama Section
K. E. Hapgood, chairman; W. G. Parrott, Jr., secretary; East Tennessee Section
J. Coleman Jones, chairman, Florida Section
J. O'D. Shepherd, chairman; J. M. Flanigen, secretary; T. W. Fitzgerald; Georgia Section
J. M. Houchens, chairman; J. F. Miller, secretary; Louisville section
George F. Leake, chairman, Memphis Section
B. M. Anthony, vice-chairman; H. W. Hutchcraft, secretary; Muscle Shoals Section
F. E. Johnson, secretary, New Orleans Section
F. S. Fourakre, chairman, North Carolina Section
F. W. Smith, chairman; L. Saunders, secretary; Virginia Section

Vice-President Maxwell presided. An invitation to the national board of directors to hold the 1941 summer convention of the AIEE at Atlanta, Ga., was prepared and approved. The committee expressed its approval of the proposal of the Middle Eastern District that the 1941 winter convention be held in Philadelphia. The question of a District meeting was referred to the District co-ordinating committee for study and recommendation.

J. Coleman Jones was elected to represent the District on the national nominating committee. He was given no instructions by the committee.

During discussion of Section activities, it was agreed that Sections scheduling outstanding speakers should notify the District secretary, in order that other Sections and Branches might, if they desired, arrange meetings for the same speaker.

The following were appointed as members of the District co-ordinating committee:

J. M. Flanigen, K. E. Hapgood, F. E. Johnson, J. O'D. Shepherd, L. L. Patterson; ex officio, F. R. Maxwell, Jr., and A. S. Hoefflin.

A committee was appointed to draw up suitable resolutions in memory of E. D. Wood, vice-president of the District before his death November 9, 1939. Other topics of District interest were discussed.

Buckley Succeeds Beggs as Foundation Chairman

Following the death on November 23, 1939, of Professor G. E. Beggs, newly elected chairman of The Engineering Foundation, O. E. Buckley (M'19, F'29) vice-chairman of the Foundation, was elected chairman by the action of the executive committee of the organization. F F Colcord was elected vice-chairman, and W. I. Slichter (A'00, F'12) one of the AIEE representatives on the board of trustees, was elected to fill the vacancy on the executive committee. K. H. Condit was made chairman of the research procedure committee, of which Doctor Buckley becomes a member ex officio. and E. M. T. Ryder was appointed to complete the membership of the committee.

A full list of the officers, trustees, and committees of Engineering Foundation appeared in the December 1939 issue, page 531. A biographical sketch of Doctor Buckley appeared in the same issue, page 537, in connection with his appointment as vice-chairman of the Foundation.

Future Meetings of Other Societies

American Chemical Society. Annual meeting, April 8–12, 1940, Cincinnati, Ohio.

American Institute of Mining and Metallurgical Engineers. 152d annual meeting, February 12–15, 1940, New York, N. Y.

American Physical Society. 233d meeting, February 22–24, 1940, New York, N. Y.

American Society for Testing Materials. Committee week and spring meeting, March 4–8, 1940, Detroit, Mich.

American Society of Civil Engineers. Annual meeting, January 17–20, 1940, New York, N. Y.

American Society of Heating and Ventilating Engineers. 46th annual meeting, January 22–26, 1940, Cleveland, Ohio.

American Society of Refrigerating Engineers. Annual meeting, January 17–19, 1940, Chicago, Ill.

Electrochemical Society. Spring meeting, April 24–27, 1940, Wernersville, Pa.

National Electrical Manufacturers Association. Mid-winter conference, February 5–9, New York, N. Y.

Society of Automotive Engineers. Annual meeting, January 15–19, 1940, Detroit, Mich.

New Heads for General Electric Company

RETIREMENT of Gerard Swope (A'99, F'22) president, and Owen D. Young, chairman of the board, was announced at a recent meeting of the directors of the General Electric Company. New officers elected at that time, who assumed their duties January 1, are Charles E. Wilson, formerly executive vice-president, who becomes president, and Philip D. Reed, formerly assistant to the president, who becomes chairman of the board. Shown here from left to right are Mr. Young, Mr. Reed, Mr. Swope, and Mr. Wilson. Mr. Wilson began his career in 1899 as office boy for Sprague Electric Company, former constituent company of G.E., and has since served in most functions of the organization and in many capacities, becoming executive vice-president in 1937. Mr. Reed, who is an electrical-engineering graduate (University of Wisconsin, 1921) and a member of Tau Beta Pi, holds the degree of doctor of laws from Fordham University. He entered General Electric's law department in 1926, and was made assistant to the president in 1937. Mr. Young and Mr. Swope, both of whom assumed their positions in 1922, have been made respectively honorary chairman of the board and honorary president. A biographical sketch of Mr. Swope appears on page 47.

"Engineering Audits" Proposed for Public Works

A proposed "Public Projects Efficiency Bill" was described by State Senator Thomas C. Desmond of Newburgh, N. Y., before a luncheon meeting of the American Institute of Consulting Engineers held in New York City, December 6, 1939. The bill is intended to encourage, and specifically to permit, state and local units of government to hire independent engineers "of outstanding reputation . . . to double check in advance the economy, safety, desirability, feasibility, and efficiency of public works projects." The bill is intended specifically to enable the procurement of an independent estimate of the extent of the benefit, if any, that may be expected to accrue to the public as the result of such public works, either generally or as compared with their probable cost.

The bill provides that findings of the independent engineers, although not binding on the unit of government concerned, must be made public, thus revealing any unsound or undesirable features so that the public may take action accordingly. Characterizing the Florida Ship Canal and Passamaquoddy power projects as "outstanding national examples of waste of public moneys which intelligent engineering advice in advance would have prevented," Senator Desmond described his bill as being "aimed toward reduction in the cost of government and designed to insure social and economic as well as engineering soundness in public works projects." He stated further that "the checks provided by this bill on the work of those proposing public works projects are similar to those which auditors make of the accounts of financial officers. Financial audits stimulate accuracy and so will engineering audits."

The Senator expressed the hope that his bill would serve as a model for other states.

Doctor D. C. Jackson (A'87, F'12, past president) of Cambridge, Mass., presided at the luncheon as president of the American Institute of Consulting Engineers.

Columbia Establishes Egleston Medal

The Egleston Medal, commemorating Professor Thomas Egleston, pioneer in engineering education, has been established by the Columbia University Engineering Schools Alumni Association, to be awarded annually to an alumnus who has "distinguished himself either in the furtherance of his branch of the profession in the development of processes or of technique, or in the application of engineering principles."

The first awards were made in 1939, in connection with the celebration of the 75th anniversary of the School of Engineering, to 12 outstanding graduates. Gano Dunn (A'91, F'12) president of the J. G. White Engineering Corporation and of Cooper Union, was one of those honored. A biographical sketch of Doctor Dunn appeared in the November 1939 issue, page 489

Honorary Members Named by Civil and Mechanical Engineers

The American Society of Civil Engineers and The American Society of Mechanical Engineers have each recently conferred honorary membership upon several distinguished engineers.

The ASCE has named the following, all members of the society:

W. J. B. Binnie, senior partner of Sir Alex. Binnie Son and Deacon, London, Eng., and president of The Institution of Civil Engineers of Great Britain.

J. M. R. Fairbairn, retired chief engineer of the Canadian Pacific Railway, Montreal, Que., Can.

H. S. Crocker, consulting engineer, Denver, Colo.

H. S. Jacoby, Washington, D. C., professor emeritus of bridge engineering at Cornell University

T. U. Taylor, dean emeritus of engineering at University of Texas, Austin

Formal presentation of certificates of honorary membership will be made at the annual meeting of ASCE, New York, N. Y., January 17–20, to all except Mr. Binnie, whose certificate will probably be presented in England at some later time.

Named by ASME were:

D. S. Kimball, dean emeritus of engineering, Cornell University, Ithaca, N. Y.

E. J. Prindle (A'06, M'20) retired patent attorney and mechanical engineer, East Orange, N. J.

C. T. Main, industrial engineer, Boston, Mass.

H. H. Vaughan, consulting engineer and president, Canadian Foreign Investment Corporation, Montreal, Que., Can.

Certificates were presented at the annual meeting of the society at Philadelphia, Pa., December 4–8, 1939. A biographical sketch of Mr. Prindle appears on page 48.

Also at the recent meeting, the ASME Gold Medal, highest honor of the society, was presented to J. E. Gleason, president, Gleason Works, Rochester, N. Y., for "distinguished service to the automotive industry by making possible better and safer gear drives."

Registration at the first ASME annual meeting to be held elsewhere than in New York City was 2,224. The banquet held in connection with the meeting was the largest in the society's history. An unusually large number of technical papers, over 100, were presented, with particular interest shown in the subject of power generation.

Engineering Education Report Issued by ECPD

That the engineering school, for years a stepchild of the university, has fought its way upward and stands today on the level of the university and in some cases on an even higher level is the general theme of

the report on "Present Status and Trends of Engineering Education in the United States," by Doctor Dugald C. Jackson, (A '87, F '12) emeritus professor of Massachusetts Institute of Technology, issued November 25, 1939, by the Engineers' Council for Professional Development, with the aid of funds supplied by the Carnegie Foundation for the Advancement of Teaching. The report is one of the valuable by-products of the task of accrediting curricula in engineering that has been accomplished with such notable success during the last few years by the committee on engineering schools of ECPD.

Doctor Jackson's report may be divided roughly into four parts, to which an appendix has been provided by Allen W. Horton, Jr., who acted as secretary to the committee during the period in which the accrediting procedure was developed and put to the test and the data were collected. In the early chapters of the report Doctor Jackson traces the history of developments that led up to the accrediting program, summarizes the Mann, Wickenden, and Potter reports that have played important roles in that development, and sketches briefly the status of engineering education in America in 1939. He next turns his attention to the committee on engineering schools of ECPD, to the procedure it adopted in its task of accrediting curricula, and to comments on some of the perplexing problems it had to face and the progress of the committee's own thinking and methods that resulted from study of these problems.

The data themselves, which cover 679 curricula in 139 institutions, assembled, coordinated, and analyzed in the form of tables and charts, with Doctor Jackson's comments on what they signify to him, occupy the third portion of the report. These data were gathered for the purpose of the accrediting program, which they usefully served, but their very existence constituted such a rich store of information of value to engineers and educators, and was so fruitful for the improvement of engineering education, that the committee was able to secure from the Carnegie Foundation for the Advancement of Teaching the funds necessary to put them in shape for public use.

Copies of the paper-bound report, which contains 177 pages, may be obtained for $1 each from the Engineers' Council for Professional Development, 29 West 39th Street, New York, N. Y.

Current Items From American Engineering Council

Joint Committee Studying Future of AEC

Organization of the special joint committee formed to consider the future form and scope of American Engineering Council took place at its first meeting, held November 27, 1939, in New York, N. Y. The group, appointed at the suggestion of Council's president and executive committee, includes three representatives of each of the three founder societies that are Council's chief supporters—the American Society of Civil Engineers, The American Society of Mechanical Engineers, and the American Institute of Electrical Engineers—plus three men representing AEC. All members were present and, in addition, Council's President William McClellan and Secretary F. M. Feiker.

The meeting opened with a statement by Doctor McClellan outlining the background leading to the call for formation of the committee. He discussed the need for professional unity among engineers and the necessity for having some interprofessional body to advance the public understanding of the profession of engineering, with special reference to the part that engineers should play in solving social and economic questions upon which they are peculiarly qualified to advise. American Engineering Council, he pointed out, is not a superorganization, but a functional service group for its members that is devoted to public service rather than to the specialized technical and engineering problems of the respective engineering societies. This membership now comprises over 50 national, state, and local technical organizations.

Doctor McClellan then reviewed the constant difficulties experienced in financing the work of AEC, in keeping the rank and file of member societies informed as to its accomplishments, and in meeting the many opportunities for service presented to Council, many of which must of necessity be deferred because of lack of funds.

A lengthy discussion followed Doctor McClellan's talk, from which emerged a number of major ideas that may be summed up as follows:

1. Some organization is essential, similar in character to the American Medical Association and the American Bar Association, to work toward the dual objectives of interprofessional relations among engineers and a combined professional approach to public problems.

2. The present AEC represents one method of providing such a body.

3. There should be closer co-ordination between the activities of AEC in its specialized public relations field and the various committees of its member organizations set up for similar or co-ordinate objectives such as, for example, the general advance of professional standards and the economic status of engineers, and interrelations between education and engineering.

4. The engineering profession as a whole has yet to find a means of advising the younger engineers on questions involving their future professional status.

The committee then organized, electing Doctor John C. Parker (AIEE A'04, F'12) chairman and T. F. Barton (AIEE A'12, F'30) secretary. Three subcommittees were authorized to consider questions of membership, scope, and finance, and to be headed, respectively, by Malcolm Pirnie, (ASCE), Harold M. Lewis (ASCE), and John S. Dodds (AEC). To meet the immediate financial situation it was recommended that each of the three founder societies contribute not less than $8,300 to AEC during the year 1940.

U. S. Calls Parleys on Power Grid System

Starting on December 5 the National Power Policy Committee, of which Secretary of the Interior Harold L. Ickes is chairman, began a series of conferences in Washington with the officials of some 50 large public utility companies operating in the eastern part of the United States for the purpose of exploring the possibilities of constructing a series of high-voltage power lines tying together the larger generating plants and power-consuming centers in this area, including both private and public developments.

While no definite plan has been made public, the proposal envisions connecting links that would make it possible to interchange power whenever necessary between such major load centers as Boston, New York, Philadelphia, Washington, Buffalo, Cleveland, Detroit, Chicago, St. Louis, and possibly Birmingham, as well as intervening cities. Connections would be made with all major generating stations, both steam and hydro, without regard to whether they are controlled by private capital, municipalities, or the Federal Government. Construction would cost in the neighborhood of $500,000,000, according to preliminary estimates.

A similar plan has been in operation in England for a number of years, being popularly known as the grid system. Its application to this country is proposed as a method of providing greater flexibility in meeting power demands resulting from future industrial expansion, particularly in case of war. Critics of the plan, as applied here, protest that there is now, in existence or under construction, ample generating capacity in each of the localities to meet all predictable future demands, and that the expenditure of such a large amount would impose an unnecessary financial burden upon consumers of electricity. Its proponents take the view that the future growth of power demand will be at an accelerating rate and that the rate of construction can be adjusted to actual needs for the new facilities. They are also understood to be relying strongly on the national defense argument, on the assumption that, even though temporarily uneconomic, the grid can be justified as a safeguard against the power shortages experienced by American industry during the last war.

If it be assumed that the economic objection is sound, and the grid plan is nevertheless adopted, the private utilities will be facing a dilemma. They will be forced to choose between themselves financing and constructing unneeded facilities, or letting the government do so and thus taking one more step in the direction of public ownership of power facilities. In England the grid is operated by an independent board composed of representatives of both public and private operating companies, and it is possible that some similar system of control might be worked out in this country, but this solution would have numerous difficulties to hurdle.

Standards

Rubber-Insulation Standard Withdrawn. Under date of August 11, 1939, the American Standards Association issued notice that on recommendation of sectional committee *C*8, "Insulated Wires and Cables," the American Standard entitled "Specifications for Class *A* 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes," *C*8.4 (1936) has been withdrawn. The action of the ASA is based on the fact that the standard had dropped out of general use, having been displaced by *C*8.17 "Class *OA* 30 Per Cent Rubber Insulation for Wire and Cable for General Purposes."

AIEE Representatives on Electrical Standards Committee. At the August meeting of the AIEE board of directors, the following representatives and alternates were appointed to serve on the electrical standards committee of the ASA: R. E. Hellmund, Westinghouse Electric and Manufacturing Company, V. M. Montsinger, General Electric Company, H. S. Osborne, American Telephone and Telegraph Company; Alternates: E. L. Moreland, Massachusetts Institute of Technology, E. B. Paxton, General Electric Company, H. E. Farrer, AIEE headquarters.

Basic Principles for Rating of Electrical Machinery and Apparatus. Co-ordinating committee 4 of the standards committee, P. L. Alger, chairman, held a session at the AIEE Middle Eastern District meeting in Scranton, Pa., October 11, 1939. A final report may be ready for publication in January 1940.

Joint Committee on Insulation Co-ordination. At the October 17 meeting of the AIEE standards committee, an invitation was presented suggesting that the Institute co-operate in the work of a joint committee of Edison Electric Institute and National Electrical Manufacturers Association now dealing with the subject of insulation co-ordination. The standards committee recommended the appointment of four men to serve on the joint committee. This recommendation was approved by the board of directors on October 27, 1939. The appointments made were as follows: Stanley Stokes, Union Electric Company of Missouri, R. T. Henry, Buffalo Niagara Electric Corporation, A. C. Monteith, Westinghouse Electric and Manufacturing Company, D. M. Jones, General Electric Company.

Standard Voltages and Currents. Co-ordinating committee 2 of the AIEE standards committee, under the chairmanship of C. A. Powel, Westinghouse Electric and Manufacturing Company, made its preliminary report at the October 17, 1939, meeting of the standards committee on "voltages below 100." A thorough survey of the field is being made by a subcommittee under D. F. Miner. A questionnaire has been sent out for the purpose of assembling existing information. Data have already been received from a number of fields, including the following: central stations, signaling, railways and busses, therapeutic devices, telephone, welding, lighting, portable tools and devices, electronic devices. This preliminary survey indicates that there are now 42 well-established voltages in use in the United States in the range of 1 to 100 volts. There appear to be very few standards at present even for specific types of apparatus.

Letter Symbols for Electric and Magnetic Quantities

Abstracted From a Report Prepared as a Proposed Revision of AIEE Standard 17*g*1 and Soon to Be Available in Printed Report Form for Criticism (See Accompanying Text)

Quantity	Letter Symbol*	Name of Unit
Admittance	Y, y	mho
Angular frequency	ω	
Angular velocity	ω	
Capacitance	C	farad, microfarad, micromicrofarad
Capacity (see capacitance)	C	
Charge, quantity	Q	
surface density of	σ	
volume density of	ρ	
Conductance	G, g	
Conductivity	γ	
Coupling coefficient	ϵ	
Current	I, i	ampere, milliampere
Current density (see linear current density)	S	
Difference of potentials	E, e	volt, microvolt, kilovolt
Dielectric constant	K, or ϵ	
Dielectric constant of free space	K_0 or ϵ_0	
Dielectric flux	Ψ	
Dielectric flux density	D	
Efficiency	η	
Elastance	S	
Electric displacement	D	
Electric potential	E, e	volt
Electric tension (see voltage)	E, e	
Electric intensity	$\mathcal{E}$	
Electric field intensity	$\mathcal{E}$	
Electromotive force	E, e	volt
Electrostatic capacity (see capacitance)	C	farad
Electrostatic flux density	D	
Electrostatic induction	D	
Energy (see also work)	W	joule, watt-hour
Flux density:		
electrostatic	D	
magnetic	B	gauss
Flux, dielectric	Ψ	
magnetic	Φ	maxwell, weber
Frequency	f	cycle per second, hertz
Frequency, rotational	n	
Impedance	Z, z	ohm
Inductance, self	L	henry
Inductance, mutual	M $L_{1,2}$	henry
Intensity of magnetization	J	
Linear current density	A	
Magnetic field strength	H	oersted
Magnetic flux	Φ	maxwell, weber
Magnetic flux density	B	gauss
Magnetic induction	B	gauss
Magnetic intensity	H	oersted
Magnetizing force	H	oersted
Magnetomotive force	M	ampere-turn, gilbert
Number of conductors	N	
Number of turns of a winding	N	
Number of poles	p	
Number of phases	n or m	
Period	T	
Permeability	μ	
of free space	μ_0	
Permeance	Λ	
Permittance (see capacitance)	C	
Permittivity (see dielectric constant)	K, ϵ	
Phase angle	φ	
Power, active	P (P_p)	p, watt
apparent	None yet agreed on	
reactive	Q (P_q)	var
Quantity of electricity	Q	coulomb
Reactance	X, x	ohm
Resistance	R, r	ohm
Resistivity	ρ	ohm-centimeter
Reluctance	θ	
Reluctivity	ν	
Rotational frequency	n	
Self-inductance	L	henry
Slip	s	
Space permeability	μ_0	
Specific inductive capacity	K or ϵ	
Susceptance	B, b	mho
Susceptibility	κ	
Speed of rotation	n	
Temperature	t, θ	degree
Temperature, absolute	T	degree
Time	t	second
Time constant	τ	
Voltage	V, v; E, e	volt
Work (see energy)	W, w	erg, kilowatt-hour

* All letter symbols are to be printed in *italic* letters, except when used as vectors, which are printed in **bold face** letters.

NOTES: 1. Where distinctions between maximum, instantaneous, effective (root-mean-square), and average values are necessary E_m, I_m, and P_m are recommended for maximum values; e, i, and p for instantaneous values, E and I for effective (rms) values, and P for average value.

2. It is recommended that quantities per unit volume, area, length, etc., be represented as far as practical by lower-case letters, corresponding to upper-case letters which will represent the total quantities.

3. Where a distinction between electromotive force and difference of potential is necessary or desirable, the symbols E, e and V, v, respectively, may be used.

Precipitation Rate on Flashover Tests. For quite a number of years a conflict has existed in the AIEE standards in the specification of the precipitation rate for wet flashover. The insulator standards have specified 0.2 inch per minute precipitation whereas the corresponding tests on bushings are to be made at an 0.1-inch rate. This matter was referred by the standards committee at the October 17 meeting to co-ordinating committee 3 (insulation testing and co-ordination) for consideration and report to the standards committee.

Organization of Sectional Committee on Voltages Below 100. An invitation has been received by the AIEE from the ASA suggesting the appointment of representatives to serve on a sectional committee on "Standardization of Voltages Below 100." The following appointments were recommended and have been approved by the board of directors: D. F. Miner, Carnegie Institute of Technology, A. M. de Bellis, Consolidated Edison Company of New York, Inc., A. H. Schirmer, Bell Telephone Laboratories, Inc. The AIEE subcommittee on voltages below 100 referred to in an earlier paragraph will co-operate with the sectional committee when it gets under way.

New Representatives on Sectional Committee on Wires and Cables. Because of the resignation of J. B. Whitehead and the death several years ago of E. B. Meyer, the standards committee, at its meeting of October 17, recommended the appointment of two representatives to serve with W. A. DelMar, chairman of the AIEE delegation. The recommendations approved by the directors were as follows: C. L. Dawes, Harvard University, and W. N. Zippler, Gibbs and Cox, Inc.

Sponsorship for Welding Goes to AWS. The Institute and NEMA have resigned their joint sponsorship of the sectional committee on electric welding apparatus, *C52*, in favor of a sole sponsorship by the American Welding Society. It is hoped that the sectional committee will shortly undertake a revision of the two existing American Standards, *C52.1* and *C52.2* "Electric Arc Welding Apparatus" and "Resistance Welding Apparatus."

New Representatives on Rotating Electrical Machinery. To fill the vacancy in the AIEE delegation on the sectional committee on rotating electrical machinery made by the death of A. E. Kennelly, the standards committee at its meeting of October 17 recommended the appointment of Reinhold Rudenberg, of Harvard University. This appointment was confirmed at the October meeting of the directors.

Revision of Letter Symbols for Electric and Magnetic Quantities. Sectional committee *Z10* "letter symbols and abbreviations for science and engineering" submitted through its chairman, J. Franklin Meyer, at the October 17 meeting of the standards committee, a revised report of the present AIEE standard *17g1*. On recommendation of Doctor Meyer, the standards committee accepted the report for publication in pamphlet form as a suggested revision of the existing AIEE and American standard. An abstract of the report presenting a list of quantities with recommended symbols appears elsewhere in this section. For purpose of criticism, copies of the complete report will be available in January and may be had without charge on application to H. E. Farrer, secretary, AIEE standards committee, 33 West 39th Street, New York, N. Y.

There is one particularly notable development in this report; it is the inclusion of a statement on "general principles". Identical statements will be included in all other subcommittee reports of the sectional committee. The statement is drawn up as a guide to authors in the use of symbols.

Personal Items

F. M. Feiker (M'34) since 1934 executive secretary of American Engineering Council, has been appointed dean of engineering of George Washington University, Washington, D. C., according to an announcement received as this issue of ELECTRICAL ENGINEERING goes to press. A biographical sketch of Doctor Feiker will appear in the February issue.

Philip Torchio (A'95, F'12) retired vice-president, Consolidated Edison Company of New York, Inc., has been awarded the Edison Medal for 1939. The medal, highest honor of the AIEE, will be presented on Wednesday evening, January 24, at the winter convention. It is awarded to Mr. Torchio for "distinguished contributions to the art of central-station engineering and for achievement in the production, distribution, and utilization of electrical energy." He was born at Vercana, Como, Italy, August 2, 1868, and received the degree of bachelor of arts at the University of Pavia, 1890, and the degrees of mechanical engineer and electrical engineer from the Royal Polytechnic of Milan, having taken a special electrical-engineering course at the Institute Carlo Erba. He came to New York in 1893 and was employed as draftsman and chief draftsman by the Sprague Electric Elevator Company, 1893–95. In 1895 he joined the engineering staff of the Edison Electric Illuminating Company of New York, continuing with that company and its successors, the New York Edison Company and Consolidated Edison Company of New York, until his retirement in 1938. He held the positions of engineer of economics, 1895–1901; engineer of distribution, 1901–05; chief electrical engineer 1905–24; vice-president 1924–38, and from 1905 to 1938 was also consulting engineer for five allied companies. He has made numerous contributions to technical literature, has been member and chairman of many AIEE technical committees, and is also a member of the Franklin Institute, Illuminating Engineering Society, Associazione Elettrotechnica Italiana, and New York Electrical Society (past president).

PHILIP TORCHIO

Gerard Swope (A'99, F'22) has retired as president of the General Electric Company, Schenectady, N. Y. He was born at St. Louis, Mo., December 1, 1872, received the degree of bachelor of science in electrical engineering at Massachusetts Institute of Technology in 1895, and has received the honorary degrees of doctor of science from Rutgers University (1923), Union College (1924), Washington University (1932); doctor of laws, Colgate University (1927), and doctor of engineering, Stevens Institute of Technology (1929). His first engineering experience was as a helper at General Electric Company, Chicago, Ill., in 1893. In 1895 he was employed by Western Electric Company, Chicago, becoming manager of the St. Louis office, 1899; in 1906 he returned to Chicago and in 1908 went to New York as general sales manager, becoming vice-president and director in 1913. During the World War he was a member of the general staff of the United States Army, serving as assistant director of purchases, storage, and traffic. In 1919 he was made president of International General Electric Company. He became president of the General Electric Company in 1922, and since 1927 has been chairman of the board of International General Electric. He is also a member of various other scientific and engineering societies. Mr. Swope was recently appointed chairman of the New York City Housing Authority, and will assume the duties of that position about March 1.

L. F. Morehouse (M'16, F'20) has retired as technical representative in Europe for American Telephone and Telegraph Company and Bell Telephone Laboratories. He was born October 21, 1874, at Big Rapids, Mich., and received the degrees of

bachelor of science in electrical engineering (1897) and master of arts (1904) and the honorary degree of doctor of engineering (1934) from the University of Michigan. Between 1897 and 1904 he was engaged in graduate study and was an instructor in physics, at Washington University, St. Louis, Mo., 1901, and at the University of Michigan, Ann Arbor, 1902–04. He was instructor and later assistant professor of electrical engineering at Michigan 1904–06. In 1906 he went to London, Eng., as transmission engineer for Western Electric Company, returning to New York, N. Y., in 1909 as equipment engineer for the American Telephone and Telegraph Company. In 1919 he became equipment development engineer for the company, and in 1933 assistant director of systems development for Bell Telephone Laboratories. He has been European representative for the two organizations with headquarters in London, England, since 1935. Doctor Morehouse was a manager of the AIEE 1919–23, and vice-president 1924–26. He is also a member of the American Association for the Advancement of Science, The Institution of Electrical Engineers of Great Britain, Sigma Xi, and Tau Beta Pi.

J. E. Hobson (A'36) central-station engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded honorable mention in the selection by Eta Kappa Nu, honorary electrical-engineering society, of America's outstanding young electrical engineer for 1939. A native (1911) of Marshall, Ind., he received the degrees of bachelor of science (1932) and master of science (1933) in electrical engineering from Purdue University, and doctor of philosophy (1935) from California Institute of Technology. He was a graduate assistant and teaching fellow at the latter institution 1933–35; assistant professor of mathematics, Earlham College, Richmond, Ind., 1935–36; and instructor in electrical engineering, Armour Insitute of Technology, Chicago, Ill., 1936–37. Since 1937 he has been with the central station section of the Westinghouse industry-engineering department. He is also a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

E. J. Prindle (A'06, M'20) retired patent attorney and engineer, East Orange, N. J., has been made an honorary member of The American Society of Mechanical Engineers. He was born at Washington, D. C., November 5, 1868, and received the degrees of mechanical engineer, Lehigh University, 1890, and bachelor of laws, 1902, master of laws, 1904, from the National University, and the honorary degrees of doctor of laws, 1930, National University, and doctor of engineering, 1934, Lehigh University. From 1890 to 1899 he was an assistant examiner in the United States Patent Office, Washington, D. C., leaving that position to enter the practice of patent law, which he continued in Washington, D. C., until 1905 and in New York until his recent retirement. He was senior member of the firm of Prindle, Wright, Neal, and Bean. He is also a member of the ASME, American Institute of Mining and Metallurgical Engineers, other technical societies, and various legal organizations, and was for many years chairman of the patents committee of American Engineering Council.

C. E. Shannon (A'39) assistant in mathematics, Massachusetts Institute of Technology, Cambridge, has been awarded the Alfred Noble prize for his paper "A Symbolic Analysis of Relay and Switching Circuits." The award, an account of which appears on page 42, will be presented during the AIEE winter convention in New York, N. Y., January 22–26. Mr. Shannon was born April 30, 1916, at Petoskey, Mich., and received the degree of bachelor of science in electrical engineering from

C. E. SHANNON

the University of Michigan, 1936. Since 1936 he has been engaged in graduate study at MIT, at the same time acting as a research assistant in electrical engineering, 1936–38; research assistant on a special project summer of 1938; and assistant in mathematics, 1938–39. He is also a member of the Institute of Radio Engineers and of Sigma Xi, and was an Enrolled Student in the AIEE when the prize-winning paper was presented and published.

C. K. Gieringer (A'35) chief electrical engineer, Liebel-Flarsheim Company, Cincinnati, Ohio, has been awarded honorable mention in the selection by Eta Kappa Nu, honorary electrical-engineering society, of America's outstanding young electrical engineer for 1939. A native (1907) of Miamitown, Ohio, he holds the degrees of electrical engineer (1932) and master of electrical engineering (1934) from the University of Cincinnati. He was an assistant in the research laboratory of the Detroit (Mich.) Edison Company, 1930–32 and a teaching fellow at the University of Cincinnati, 1932–34, and since 1934 has been with the Liebel-Flarsheim Company, as experimental electrical engineer, and chief electrical engineer. He received the Middle Eastern District prize for initial paper in 1934 for a paper on "A New A-C Null Indicator." He is also a member of the Institute of Radio Engineers, Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

D. C. Hosfeld (A'15, M'31) has retired as plant employment engineer, American Telephone and Telegraph Company, New York, N. Y. He was born in Shippensburg, Pa., September 10, 1883, and educated in Virginia. In 1897 he became an installer for the Bell Telephone Company of Pennsylvania, at Shippensburg. He continued with that company as equipment installer, 1901; wire chief, 1907; plant superviser, 1908; district plant superintendent, 1911; plant methods superintendent, 1920; and division equipment superintendent, 1922. In 1925 he went to Montreal, Que., as division plant superintendent for the Bell Telephone Company of Canada, and the following year became plant results engineer for the American Telephone and Telegraph Company, continuing in that position until 1937. He has since been plant training engineer and plant employment engineer.

Gano Dunn (A'91, F'12) president, J. G. White Engineering Corporation, New York, N. Y., and president of Cooper Union for the Advancement of Science and Art, was one of 12 outstanding engineering graduates of Columbia University to be awarded the Egleston Medal presented for the first time in 1939 by the Columbia Engineering Schools Alumni Association for distinguished engineering achievement. A biographical sketch of Doctor Dunn appeared in the November 1939 issue, page 489.

J. C. Parker (A'04, F'12) has been elected chairman of the committee recently appointed to consider the future form and scope of American Engineering Council. Doctor Parker, who is a vice-president of Consolidated Edison Company of New York, Inc., New York, N. Y., was president of the Institute 1938–39 and is currently chairman of its committee on planning and co-ordination.

O. E. Buckley (M'19, F'29) executive vice-president, Bell Telephone Laboratories, Inc., New York, N. Y., has been elected chairman of The Engineering Foundation by the organization's board, following the death of G. E. Beggs, newly elected chairman. A biographical sketch of Doctor Buckley, who had just been made vice-chairman of the Foundation, appeared in the December 1939 issue, page 537.

A. W. Pride (A'20) has been made manager of the porcelain department of Westinghouse Electric and Manufacturing Company at Emeryville, Calif. He was formerly sales manager of the porcelain and transformer departments and will continue as sales manager of the latter. He has been with the company continuously since 1922, and from 1915 to 1917 was in the student training course and research laboratories at East Pittsburgh, Pa.

T. F. Barton (A'12, F'30) vice-president, AIEE, and assistant manager of the New York district of General Electric Company, New York, N. Y., has been elected secretary of the committee recently formed to consider the future form and scope of American Engineering Council.

R. W. Beck (M'37) has been appointed consulting engineer by the Klickitat County, Wash., public utility district. He was formerly an electrical engineer on the Bonneville Project, Portland, Ore.

W. R. Minzner (A'38) formerly employed as instructor in mathematics, Northeastern University, Boston, Mass., is now employed as instructor in the electrical department of the Rochester (N. Y.) Athenaeum and Mechanics Institute.

C. S. Lumley (A'22, M'29) has been appointed district engineer by the Roller-Smith Company. His headquarters will be in Chicago, Ill. He was formerly electrical engineer for the Department of Public Works, City of Detroit, Mich., in charge of design of the city's new sewage-treatment plant.

E. T. B. Gross (A'34) formerly chief of the general engineering department, A. E. G.-Union Electric and Manufacturing Company, Vienna, Germany, has begun private consulting practice in Ithaca, N. Y. He had been associated with A. E. G.-Union, the Austrian division of General Electric Company, since 1924.

R. B. Kaufman (A'35) formerly research assistant, School of Engineering, Johns Hopkins University, Baltimore, Md., is now employed as an electrical engineer in the materials division of the United States Army Air Corps, Dayton, Ohio.

R. D. Miller, Jr. (A'34) formerly service manager, United Clay Products Company, Washington, D. C., has been appointed engineer, "B layout", Glenn L. Martin Company, Baltimore, Md.

A. W. Williams (A'39) has been employed as resident engineer, by the Valley Electric Membership Corporation, Natchitoches, La.

R. G. Boyles (M'34) former assistant manager of operation, Southern California Edison Company, Ltd., Los Angeles, Calif., has been appointed manager of operation. Mr. Boyles, who studied electrical engineering at Montana State College, has been with Southern California Edison since 1907, and became assistant manager of operation in 1934.

C. R. Benson (A'31) has been made official representative of the transformer department of the Pacific district of General Electric Company, with headquarters at Oakland, Calif. He was formerly meter and transformer specialist in the San Francisco office of the company.

L. T. Blaisdell (A'20, F'39) since 1936 commercial vice-president of General Electric Company, and manager of the southwestern district, with headquarters in Dallas, Tex., has been transferred to Cleveland, Ohio, as manager of the east central district. He has been associated with the company since 1904 and district manager in Dallas since 1924.

P. C. Schwantes, Jr. (A'24) has been appointed plant employment engineer, American Telephone and Telegraph Company, New York, N. Y. He was formerly plant results engineer and has been with A. T. and T. since 1924. From 1918 to 1924 he was with Western Electric Company.

J. H. Landwehr (A'19) formerly building and equipment engineer for eastern Missouri, Illinois, and Arkansas, Southwestern Bell Telephone Company, has been appointed general building and equipment engineer for the company, with headquarters at St. Louis, Mo.

A. S. Runciman (A'24, M'35) superintendent of transmission lines, Shawinigan Water and Power Company, Montreal, Que., Can., has been awarded an engineering alumni medal, for outstanding achievements in engineering, by the Council of the Engineering Alumni Association of the University of Toronto.

J. S. Wise (A'96, M'27) president, Pennsylvania Light and Power Company, Allentown, has been appointed a member of the committee on the development of Pennsylvania industry in the statewide job mobilization campaign.

C. M. Cavner (A'36) former assistant superintendent of substations, Southern California Edison Company, Ltd., Los Angeles, Calif., has been made superintendent of substations.

G. F. Maughmer (A'38) has been made manager of the Phoenix, Ariz., office of General Electric Company. He was formerly in the industrial and central stations departments of the company's Los Angeles, Calif., office.

R. E. Jerauld (A'21) has been made assistant to the manager of the Los Angeles, Calif., office of General Electric Company. He had been manager of the Phoenix, Ariz., office, since 1925, and has been with the company since 1905.

W. D. Howell (A'38) has been placed in charge of industrial power work in the San Francisco, Calif., office of Pacific Gas and Electric Company. He was formerly in the company's East Bay sales department at Oakland.

David Kalish (A'38) formerly assistant to chief engineer, Alliance Manufacturing Company, Alliance, Ohio, is now employed in the engineering department of the Curtiss Aeroplane Division, Curtiss-Wright Corporation, Buffalo, N. Y.

R. W. Masters (A'39) is a technical graduate assistant in the department of speech and phonetics, Ohio State University, Columbus, while studying for the master of science degree. He is on leave of absence from his position as junior engineer for RCA Manufacturing Company, Indianapolis, Ind.

H. L. Gerard (A'36) formerly electrical designer, Holway and Neuffer, engineers, Tulsa, Okla., is now superintendent of electrical distribution for the City of Kirkwood, Mo.

Fred Garrison (A'22, M'29) of the Los Angeles, Calif., central station department of General Electric Company, has been made meter specialist for the Pacific district.

C. S. Powell (A'38) formerly assistant electrician, Holly Sugar Corporation, Colorado Springs, Colo., is now assistant electrician at the Morony Dam of the Montana Power Company, Great Falls, Mont.

G. T. Dunklin (M'31) has been placed in charge of installment financing in the merchandising division of Westinghouse Electric and Manufacturing Company, New York, N. Y. He was formerly assistant sales manager of the division, and has been with the company since 1922.

W. M. A. Kern (A'26) formerly master mechanic, Chilean Nitrate Sales Corporation, Norfolk, Va., is employed as an electrician at the United States Naval Academy, Annapolis, Md.

R. M. Whaling (A'39) has been employed as serviceman by the International Business Machine Corporation, Sacramento, Calif.

A. L. Bohn (A'39) has been employed by the Bendix Radio Corporation, Baltimore, Md.

J. W. Pruett (A'39) is now employed as a junior engineer on the Bonneville Dam project, Portland, Ore.

S. G. Kelsey (A'39) is now junior electrical engineer for the National Advisory Committee for Aeronautics, Langley Field, Va.

L. P. Goetz (A'39) is now a valuation engineer for the Utah Power and Light Company, Salt Lake City.

Obituary

Stanley Sylvester Seyfert (A'05, M'13) head of the department of electrical engineering, Lehigh University, Bethlehem, Pa., died December 11, 1939. He was born March 19, 1881, at Strausstown, Pa., and received the degrees of bachelor of science, 1902, Kutztown State Teachers College; electrical engineer, 1904, master of science, 1909, Lehigh University; doctor of science, 1932, Massachusetts Institute of Technology. He joined the electrical-engineering department at Lehigh in 1904 as instructor, becoming assistant professor in 1909, associate professor, 1914, and professor, 1928. Since 1932 he had been head of the department and director of the curriculum. He was engineer for the Blue Mountain Electric Company, Bethel, Pa., 1907–17, and secretary and treasurer, 1917–27. He made a number of contributions to technical literature, held several patents, and was also a member of the Institute of Radio Engineers, Society for the Promotion of Engineering Education, Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

Harry S. Arnold (A'11) electrical and construction engineer Carleton Company, Inc., Brooklyn, N. Y., died July 24, 1939, according to information recently received at Institute headquarters. He was born in New York, N. Y., June 16, 1877, and took courses in various technical schools there. From 1895 to 1905 he was superintendent of electrical construction for the Commercial Construction Company, New York, after which he became an electrical inspector for the New York City Department of Education. In 1911 he became assistant electrical engineer for the department. During the period 1914–24 he was employed by various companies as construction electrical engineer, and also served in the United States Army Engineering Corps, 1917–19. He was a member of the M. J.

Daley Company, engineers and contractors, 1924–26, and 1926–29 engaged in electrical engineering and contracting with his own organization, the H. S. Arnold Company, Inc. During the next five years he had charge of design and installation of electrical systems of several large buildings in and near New York City, the most notable being the Chrysler building. In 1934 he was employed by the Federal Power Commission Washington, D. C., as engineer on its electric-rate survey, and two years later went with the Carleton Company. He was also a member of the Society of American Military Engineers, and of the New York State Society of Professional Engineers.

George Locke Crosby (A'15, M'26) vice-president and general sales manager, Roller-Smith Company, Bethlehem, Pa., died December 2, 1939. He was born at Brookhaven, Miss., July 19, 1883, and attended Millsaps College and George Washington University. He became sales engineer and manager of the Cleveland, Ohio, office of the Cutter Company in 1902, and in 1904 sales engineer for the Stanley G. I. Electrical Manufacturing Company. When the company was dissolved in 1905 he set up his own firm, Crosby, Craft, and Company, as selling agents for various companies, including the Roller-Smith Company. In 1910 he became sales engineer and manager of the Pittsburgh, Pa., office of that company, and in 1912 was transferred to the New York office. He became successively general sales manager, assistant to the president, and vice-president in charge of sales (1938). He moved to Bethlehem when the main office of the company was transferred there early in 1939. He was also a member of the Institute of Radio Engineers and the Society of Automotive Engineers.

Frank Powell Cox (A'01, M'02, F'13) retired manager of the West Lynn, Mass., works of the General Electric Company, died November 30, 1939. He was born at Terre Haute, Ind., December 31, 1866, and graduated in mechanical engineering from Rose Polytechnic Institute in 1887. He took a year of postgraduate work in electricity at Johns Hopkins University, and in 1889 was employed by the Kester Electric Company, Terre Haute. In the latter part of the same year he entered the testing department of the Thomson Electric Welding Company, at Lynn, Mass. The following year he was put in charge of the meter-testing department of the Thomson-Houston Company, successor to the preceding company and one of the forerunners of the General Electric Company, and some years later became engineer of the meter department of the latter. He became manager of the West Lynn works in 1920 and continued in that position until his retirement in 1935. He held a number of patents, mostly for meter improvements, and had contributed to technical literature and been active on several AIEE committees.

Fred James Cornford (A'23) construction engineer, Ohio Power Company, Power, West Va., died November 5, 1939. He was born at Brighton, Eng., June 9, 1885, and studied electricity at the London Polytechnic Institute. From 1899 to 1904 he was an apprentice with Page and Miles, electrical contractors, Brighton. Coming to New York, N. Y., in 1904 he became an electrician for S. Edward Eaton and Company, and three years later was employed by the B. and C. Electrical Construction Company, Utica, N. Y. From 1910 to 1914 he was with the Electric Shop, Inc., in Buffalo, N. Y., in charge of installation of electrical equipment in industrial plants and in the Buffalo Technical High School. During 1914–17 he was foreman of electrical construction for Woodmancy and Davidson, Chicago, Ill., and for F. Work, electrical contractor, Cleveland, Ohio. He was employed in 1917 by the American Gas and Electric Company, as general electrical foreman of construction at the Windsor power plant, Wheeling, W. Va., and continued with that company and various affiliates until about two years before his death, when he became associated with the Ohio Power Company.

Charles Crumer Hogshead (A'35) power engineer, Appalachian Electric Power Company, Roanoke, Va., died March 14, 1939, according to information recently received at Institute headquarters. He was born December 28, 1869, at Mount Crawford, Va. His electrical training was secured through correspondence courses. He was employed for some years by the Staunton, Va., street car company, later becoming assistant engineer of power plants for the Lynchburg (Va.) Traction and Light Company. While holding that position he spent some time with the Montgomery (Ala.) Traction Company, an affiliated organization. In 1907 he became chief engineer in charge of power plants for the Roanoke Railway and Electric Company, continuing in that position until 1925, when he became divisional power engineer in charge of power production and sales, for the Appalachian Electric Power Company, parent organization of the various operating companies by which he had been successively employed. He was an Associate of the Institute 1911–12, and was reinstated in 1935.

Ralph E. Sawyer (A'30) senior engineer, Equitable Gas Company, Pittsburgh, Pa., died October 29, 1939 at Buxton, Maine. He was born at Buxton, March 10, 1896, and was graduated from the University of Maine in 1917 with the degree of bachelor of science in electrical engineering. From 1917 to 1920 he was a traffic engineer with the American Telephone and Telegraph Company, New York, N. Y., later becoming a traffic engineer for the Ohio Bell Telephone Company, and in 1928 being transferred to the International Telephone and Telegraph Company. During the period 1931–35 he held various positions and in the latter year was appointed associate personnel research specialist for the Federal Resettlement Administration, on a survey of Administration personnel in the State of Louisiana. During 1936 he was employed as assistant valuation engineer by the New York State Public Service Commission and as engineer on the Federal Communications Commission's investigation of the American Telephone and Telegraph Company.

Louis Benedict Marks (A'90, M'95, F'13) retired consulting engineer in illumination, died at New York, N. Y., November 22, 1939. He was born at New York, January 25, 1869, and received the degrees of bachelor of science, 1888, from the College of the City of New York and of mechanical engineer, 1889, and master of mechanical engineering, 1890, from Cornell University. From 1890 to 1893 he was lighting expert with the Washington Carbon Company, Washington, Pa. In 1893 he invented and was granted basic patents on an "enclosed arc" lamp, for which he was awarded a gold medal at the Paris Exposition in 1900. During most of his career he was engaged in private consulting practice in illuminating engineering, having designed the lighting plans for many municipal, state, and Federal buildings. He was the first president of the Illuminating Engineering Society, elected in 1906.

Arthur E. Hecker (M'30) retired general manager of municipal utilities, Poplar Bluff, Mo., died June 1, 1939, according to information recently received at Institute headquarters. He was born May 14, 1878 at Pekin, Ill., and was educated there. From 1899 to 1901 he was electrician for the Corn Products Company, Pekin. He built and operated a light plant at Tallula, Ill., 1901–07, and in 1908 became supervising and erecting engineer for the Electric and Steam Engineering Company, contracting firm at St. Louis, Mo. He was operating manager at Roodhouse, Ill., 1911–12, and for the next four years manager of the light and power plant at Russellville, Ark. He went to Poplar Bluff in 1916 as supervising engineer for the City Department of Water and Light, and in 1917 became manager of municipal utilities, having charge of design, construction, and operation of both light and water systems. He had recently retired.

Augustine Leo Donnelly (A'18) general supervisor of testing section, Philadelphia Electric Company, Philadelphia, Pa., died recently, according to information just received at Institute headquarters. He was born in Philadelphia September 16, 1885, and received the degree of bachelor of science in electrical engineering from the University of Pennsylvania in 1909. After working for a short time for the Huntingdon Valley Electric Company, Wynnecote, Pa., he entered the student test course at General Electric Company in December 1909. In 1911 he entered the employ of the Philadelphia Electric Company as a testing engineer in the laboratory. He later became assistant supervisor, then supervisor of the testing laboratory, before becoming general supervisor of the testing department.

William LeRoy Robertson (A'05) technical assistant, Philadelphia Electric Company, Philadelphia, Pa., died November 17, 1939. He was born in Derby, Pa., October 15, 1883, and completed both the mechanical engineering course (1902) and the electrical engineering course (1904) at Drexel Institute. He had been employed by the Philadelphia Electric Company continuously since 1903, first as assistant in the laboratory and later as electrical engineer.

Section Activities

As Reported by Clifford A. Faust, Mansfield, Ohio, for the Sections Committee

Cleveland, Akron, Mansfield Hold First Reunion

Nineteen years ago the Akron Section was formed, the members all being affiliated formerly with the Cleveland Section. Last March, the Mansfield Section was created from the previously organized Mansfield Division of the Cleveland Section. In view of the way the two younger Sections were formed, it was not surprising that the 1939–40 officers of all three Sections should strike on and quickly endorse the idea of holding an annual "family reunion."

The first joint meeting was held at the Portage Hotel in Akron November 14 and was pronounced a huge success. National Secretary H. H. Henline attended and gave an inspiring talk on the progress being made by the Institute. C. T. Sinclair, Institute vice-president for the Middle Eastern District, accepted an invitation to preside at the meeting. John R. Townsend, materials standards engineer of the Bell Telephone Laboratories, gave an interesting illustrated talk on "Application of High-Speed Motion Pictures to the Design of Mechanical Devices." And the festivities, which included a dinner before and refreshments after the speaking program, were enjoyed by 179 members and guests, 50 from Cleveland, 42 from Mansfield, and 87 from Akron. A feature of the meeting was a "head count," effected by having the members of each Section rise in turn.

Working a Year Ahead on Section Programs

Eight Sections of the Institute determine the programs for their meetings far enough in advance to enable them to distribute printed programs for the entire season prior to the scheduled date for the first meeting. These Sections—Michigan, Chicago, Lynn, Vancouver, Cleveland, Pittsfield, Springfield, and St. Louis—make their plans through the summer for the coming season, deciding on dates, selecting subjects for meetings, and actually engaging speakers. By arranging the meetings during the summer months, they are able to print the programs and distribute them to the members about September 1.

While considerable effort is required to plan all of the meetings for a season at one time, these Sections believe that it is more than worthwhile. In the words of one of the Section chairmen: "It places the Section in a favored position for securing speakers who are much in demand, removes the uncertainties which accompany 'short term' planning, provides members with a complete guide of activities for the season, and, of great importance, creates a feeling among the membership at large that the Section is being capably managed."

Aside from the full program for the season, the 12-page booklet currently issued by the Michigan Section gives the names of all officers and committee members and includes a complete roster of all members.

Chicago issues a large four-page folder which details the meetings for the season, gives a history of the Section, reports the number of members, cites the advantages of Section membership, invites the members to take part in committee work and to offer suggestions, and lists the names of committee members. A postcard is enclosed with the pamphlet for use by the members in proposing changes or additions in activities and for indicating their interest in committee work.

The Lynn Section presents season program, along with announcements, promotional material for certain meetings, names of the officers, and the membership committee personnel, in a six-page folder. A condensed schedule of meetings, including possible lectures, inspection trips, and technical sessions, is printed on a detachable $3^1/_4$- by $6^1/_4$-inch card.

A four-page blue folder is issued by the Vancouver Section, giving the complete schedule of meetings, listing the officers, and giving the names of all committee members. The folder gives the objective of the Institute, and states that members of kindred associations, teachers, students, and all interested are cordially invited to attend any meeting.

Cleveland issues a six-page folder listing all general meetings, and supplements this information with a complete schedule of the technical-division meetings. Names of all officers and committee chairmen are listed.

Pittsfield announces the subjects for its popular meetings and technical-lecture series on the first news letter issued in the fall. This letter also relates plans for the "Colloquia," monthly discussions which are led by qualified speakers.

Using a different plan from the others, the Springfield Section issues a stiff $2^2/_3$- by $4^1/_3$-inch card, designed to be carried in the pocket, giving the season program and listing the officers.

St. Louis follows the plan of giving all details for the year's meetings on the notice for the first meeting. The notice is printed on heavy stock and the list of meetings is confined to a 4- by 7-inch section of the notice, so that the list can be detached and retained for future reference.

Several other Sections follow the plan of giving details for one or two future meetings on the notices which are prepared for current meetings. The Wichita Section, for example, gives the details under the heading, "Prevue of Coming Attractions."

Washington and Maryland Hear Talk on Solar Energy

Members of the Washington and Maryland Sections held a joint meeting in the Capital City, November 14. After a dinner at the Hotel Harrington, the group assembled at the Natural History Building Auditorium where they heard a talk by Doctor C. G. Abbot, secretary of the Smithsonian Institute, on "Solar Energy". A total of 250 members and guests were present, 75 members from the Maryland Section, 115 from the host Section, 35 students, and 25 visitors.

Florida Electricals and Mechanicals Get Together

On October 21 the Florida Sections of the ASME and the AIEE joined the University of Florida Student Branches of the two societies for an afternoon and evening meeting, held at Gainesville. At the afternoon technical session D. P. Caldwell, division manager of the Florida Power and Light Company, Daytona Beach, spoke on "A Business Man's View of the Engineering Graduate," and L. G. Alexander presented a student paper on "The Sealed-Beam Headlight." The engineering laboratories of the University were visited at 4:30. An hour later the members enjoyed an old-fashioned barbecue, and in the evening they witnessed the Florida-Tampa football game. The meeting was one of the most successful ever held at Gainesville and was enjoyed by all who attended.

St. Louis Celebrates Its 300th Meeting

The November 15 meeting was a significant occasion for the St. Louis Section, for it was the 300th meeting of this 36-year old Section. Meeting notices carry the number of the meeting each time, so that when the 299th meeting was held the month previous the members began looking forward to the tricentennial event.

The principal speaker at the meeting was C. H. Giroux, head engineer, U. S. Engineers Office, Washington, who spoke on "The Bonneville Project." A total of 109 members and guests attended the meeting.

Oklahomans Inspect Fort Sill

Members of the Oklahoma City Section joined with members of the ASCE November 18 for one of the most interesting meetings ever held by the Section, an inspection trip to Fort Sill, the principal artillery school of the United States Army. At 3:00 p.m. the group inspected field-artillery equipment and at 3:30 Army engineers gave talks on the weapons which had just been seen. At 5:00 an inspection was made of the balloon and airplane hangers, and at 6:00 the engineers had supper at a battery mess. Following dinner, War Department training films were shown, providing a climax to a most interesting day.

Although Fort Sill is about 125 miles from Oklahoma City, many members from both societies made the trip.

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Mr. Institute Member:

To remain a healthy and robust organization, it is necessary for the Institute to acquire a steady influx of new blood among energetic engineers who have ambitions for continued advancement of the profession. You are informed each year, in the September issue of ELECTRICAL ENGINEERING, that a national membership committee is set up to direct new membership activities. You are not informed, and probably do not know, that a great many members are organized and give freely of their time toward building the membership of the Institute both in quality and in numbers within their own Sections. These men are the ones who do the real work of contacting nonmembers directly and thereby become "representatives" of the Institute among nonmember engineers. To inform the membership of the scope of this activity and to acquaint the membership of each Section with the names of its members who are at work on this assignment, the personnel of all Section membership committees for the year 1939–40 is printed on this and the facing page.

L. L. Webb

CHAIRMAN, NATIONAL MEMBERSHIP COMMITTEE

Membership

Recommended for Transfer

The board of examiners, at its meeting on December 21, 1939, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Eddy, W. N., director of electrical research laboratory, Simplex Wire and Cable Company, Cambridge, Mass.

Schoolfield, H. H., chief engineer, Pacific Power and Light Company, Portland, Ore.

Yerkes, E. P., engineer of equipment and buildings, Bell Telephone Company of Pennsylvania, Philadelphia.

3 to Grade of Fellow

To Grade of Member

Barnes, W. A., chief engineer, Dominion Electric Manufacturing Company, Mansfield, Ohio.

Hadley, H. L., electrical engineer and estimator, Allis Chalmers Manufacturing Company, West Allis, Wis.

Harkins, P. S., engineer of outside plant, The Bell Telephone Company of Pennsylvania, Philadelphia.

MacKinnon, W. J., assistant electrical superintendent, Pato Consolidated Gold Dredging, Ltd., Pato, Antioquia, Colombia, S. A.

Nelson, L. A., sales engineer, General Electric Company, New York, N. Y.

Travis, I., assistant professor, University of Pennsylvania, Philadelphia.

6 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before January 31, 1940, or March 31, 1940, if the applicant resides outside of the United States or Canada.

United States and Canada

1. North Eastern

Cayey, E. V., Westinghouse Electric and Manufacturing Company, Buffalo, N. Y.

Cook, L. W., General Electric Company, Bridgeport, Conn.

Corbett, V. P., Westinghouse Electric and Manufacturing Company, Buffalo, N. Y.

Garner, G. L., Southern New England Telephone Company, New Haven, Conn.

Hodge, T. T., Sr., Eastman Kodak Company, Rochester, N. Y.

MacIntire, H. L., Buffalo Niagara Electric Corporation, North Tonawanda, N. Y.

Sheldon, E. E., General Electric Company, Bridgeport, Conn.

Zollin, A. E., Southern New England Telephone Company, New Haven, Conn.

2. Middle Eastern

Baker, F. E., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Barto, J. P., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Batten, R. A., W. V. Pangborne and Company, Inc., Philadelphia, Pa.

Bowden, C. S. (Member), Ohio Public Service Company, Alliance, Ohio.

Brannan, A. I., Ohio Edison Company, Akron.

Coffin, L. H., Cincinnati Gas and Electric Company, Cincinnati, Ohio.

Delaney, J. J., War Department, Washington, D. C.

Garn, W. B., Westinghouse Transformer Works, Sharon, Pa.

Hager, G. Y., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Halberstadt, R. L., Bell Telephone Company of Pennsylvania, Philadelphia.

Hoover, C. (Member), Ohio Public Service Company, Sandusky.

Hutcheson, J. P., Jr., care of J. Parks Hutcheson Company, Cleveland, Ohio.

James, W. G. (Member), Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Kroeger, E., 347 East Montana Street, Philadelphia, Pa.

MacDougal, H. M., Copper Wire Engineering Association, Washington, D. C.

Martin, H. S., Fidelity Electric Company, Lancaster, Pa.

Miller, W. W. (Member), Bell Telephone Company of Pennsylvania, Philadelphia.

Myhre, C. B. (Member), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Nichols, J. J., Bell Telephone Company of Pennsylvania, Philadelphia.

Romero, R. F., Federal Power Commission, Washington, D. C.

Ruch, E. A., Jr., Public Service Electric and Gas Company, Trenton, N. J.

Ryder, G. C., Public Service Electric and Gas Company, Camden, N. J.

Seifried, A. G., B. F. Goodrich Company, Akron, Ohio.

Shank, J. S., United States Patent Office, Washington, D. C.

Yeager, B. J., Cincinnati Gas and Electric Company, Cincinnati, Ohio.

3. New York City

Baker, E. W., American Telephone and Telegraph Company, New York, N. Y.

Collis, R. E. (Member), Bell Telephone Laboratories, New York, N. Y.

Curtis, V. K., Copperweld Steel Company, New York, N. Y.

Dean, W. W., Jr., Jersey Central Power and Light Company, Morristown, N. J.

Erickson, J. R., Bell Telephone Laboratories, New York, N. Y.

Graneto, P. A., Steel and Tubes, Inc., Brooklyn, N. Y.

Hunter, E. A., American Gas and Electric Service Corporation, New York, N. Y.

Irish, J. S., Consolidated Edison Company of New York, Inc., New York, N. Y.

Krzemien, A., Childs Company, New York, N. Y.

Meredith, L. H., Rockefeller Center, Inc., New York, N. Y.

Miller, W. D., Automatic Electric Company, New York, N. Y.

Murphy, H. E., General Electric Company, New York, N. Y.

Ostergren, C. N., American Telephone and Telegraph Company, New York, N. Y.

Reintjes, J. F., Manhattan College, New York, N. Y.

Rowe, J. C. (Member), General Electric Company, Hoboken, N. J.

Schaefer, E. W., Brooklyn Union Gas Company, Brooklyn, N. Y.

Spear, L. W., Consolidated Edison Company of New York, Inc., New York, N. Y.

Strang, J. G., National Broadcasting Company, Inc., New York, N. Y.

Vogeler, R. A., Cornell Dubilier Electric Corporation, South Plainfield, N. J.

Welse, W. P., Consolidated Edison Company of New York, Inc., New York, N. Y.

Weiss, D., Jersey Central Power and Light Company, Allenhurst, N. J.

Zimmerman, C. P., American Gas and Electric Service Corporation, New York, N. Y.

4. Southern

Bowman, J. S., Memphis Light, Gas, and Water Division, Memphis, Tenn.

Boyles, K. W., Commonwealth and Southern Corporation, Birmingham, Ala.

Combs, J. M., Jr. (Member), Mississippi Power and Light Company, Jackson.

Craig, M., Jr., Memphis Light, Gas, and Water Division, Memphis, Tenn.

Deloney, H. L., Louisiana Power and Light Company, Algiers.

Fransioli, V. J., Jr., Memphis Light, Gas, and Water Division, Memphis, Tenn.

Hadsel, H., American Elevator and Machine Company, Louisville, Ky.

Harrison, J. F. (Member), Mississippi Power and Light Company, Jackson.

McNiven, J. A., Louisiana Power and Light Company, Algiers.

Milton, J. C., Mississippi Power and Light Company, Jackson.

Morgan, W. D., Memphis Light, Gas, and Water Division, Memphis, Tenn.

Profilet, W. B., Mississippi Power and Light Company, Jackson.

Sanders, W. F., Carolina Aluminum Company, Badin, N. C.

Wilkerson, C. C., Western Union Telegraph Company, Louisville, Ky.

5. Great Lakes

Anderson, C. G., Schweitzer and Conrad, Inc., Chicago, Ill.

Elliot, W. H., Cutler Hammer Inc., Milwaukee, Wis.

Higgins, T. J. (Member), Purdue University, West Lafayette, Ind.

Keeler, R. J., Commonwealth Edison Company, Chicago, Ill.

Kirk, E. L., Dow Chemical Company, Midland, Mich.

Marshall, R. B., Purdue University, West Lafayette, Ind.

O'Day, J. H., Northwestern Bell Telephone Company, Des Moines, Iowa.

Purdy, R. T., Commonwealth Edison Company, Chicago, Ill.

Trommer, C. H., Public Utility Engineering and Service Corporation, Chicago, Ill.

6. North Central

Landmesser, J. B., 2735 West 20th Avenue, Denver, Colo.

Stuart, E. V., Public Service Company of Colorado Denver.

7. South West

Baltzell, L. A. (Member), Texas New Mexico Utilities Company, Plainview, Tex.

Bostock, G. M., General Electric Company, Dallas, Tex.

Caldwell, R. W., Graybar Electric Company, Inc., Kansas City, Mo.

DeBettencourt, M. A. (Member), 402 Sidney, Houston, Tex.

Keller, R. G. (Member), University of Texas, Austin.

McDougal, I. E., Westinghouse Electric and Manufacturing Company, Wichita, Kans.

Pickens, W. B., Texas Electric Service Company, Eastland.

Reeves, L. P., Southwestern Bell Telephone Company, Tulsa, Okla.

Spreen, H. F., Texas Electric Service Company, Fort Worth.

White, J. B. (Member), International Boundary Commission, El Paso, Tex.

White, M. A., R. H. Reed Engineering Company, Abilene, Kans.

8. Pacific

Ardern, F. V., General Chemical Company, El Segundo, Calif.

Brock, A. E., Pacific Electric Manufacturing Corporation, San Francisco, Calif.

Muller, C. L., Pacific Electric Manufacturing Corporation, San Francisco, Calif.

Ottaway, C. S., Pacific Gas and Electric Company, Oakland, Calif.

Scarfe, S. W. (Member), General Electric Company, Los Angeles, Calif.

9. North West

McCown, J. F., Puget Sound Power and Light Company, Seattle, Wash.

10. Canada

Craik, O. S., Canadian International Paper Company, Gatineau Mills, Quebec.

Macdonald, J. B., British Columbia Electric Railway Company, Vancouver.

Walker, F. L., T. Eaton Company, Toronto, Ont.

Total United States and Canada, 100

Elsewhere

Maile, A. W., Railways Department, Sierra Leone, Freetown, West Africa.

Blackledge, R. S., Messrs. Veritys, Aston, Birmingham, England.

Total elsewhere, 2

Engineering Literature

New Books in the Societies Library

Electrical engineers may be interested in the following new books, which are among those recently received at the Engineering Societies Library, New York, N. Y. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the preface of the book in question.

ÜBERSPANNUNGEN UND ÜBERSPANNUNGSSCHUTZ. (Sammlung Göschen, Band 1132). By G. Fröhauf. Berlin, Walter de Gruyter and Company, 1939. 122 pages, illustrated, 7 by 4 inches, cloth, 1.62 rm. This small work explains overvoltage phenomena and their origin, discusses moving waves and surge voltages, and describes methods and apparatus for the protection of conductors and stations. Impulse processes and impulse testing of electrical windings are also considered.

THE SWITCHGEAR HANDBOOK. Volume 1—Apparatus. Edited by W. A. Coates and H. Pearce. New York and Chicago, Pitman Publishing Corporation, 1939. 190 pages, illustrated, 9 by 6 inches, cloth, $4.50. The joint product of a group of British engineers, each a specialist in the subject he discusses, this book is intended as a general guide to switchgear, considered from the point of view of the user rather than the expert designer. After a discussion of the theory, it considers the actual design of circuit breakers, fuses, switches, instrument transformers, voltage regulators, and other apparatus.

Transactions

Preprint of Papers and Discussions Comprising Pages 1–64 of the 1940 Volume

The Characteristics and Power Requirements of Spinning Frames

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NONMEMBER AIEE

THE POWER required to drive the many types of textile machines has always been an important problem confronting the manufacturer of all the textile fibers, especially the cotton-goods manufacturer, who leads all other branches of the industry.

When the majority of cotton mills were driven by steam or water power, this problem was not critical, but when the large groups of machines were broken down to individual drives and smaller groups driven by electric motors, it assumed greater importance.

The earlier designs of large motors replacing the steam engine or water wheel were extremely liberal, and the addition of a few extra machines on a large motor-driven group seldom worried the manufacturer or the motor. A greater knowledge of fundamentals and the more economical use of materials today permits the design of more efficient motors, very close to their name-plate ratings, which demands a more accurate knowledge of power requirements in applying the motors.

Advancements in the manufacture of fabrics and the breaking up of group drives into individual motor applications for greater flexibility in operation necessitates a much closer study of the power requirements of the individual machines.

The usual method of meeting these problems was to take electrical instruments to the mills and make power tests on the machines in question, recording all textile data at the same time. These data were compiled and served as a basis for determining power requirements in many other mills.

Paper number 39-103, recommended by the AIEE committee on industrial power applications, and presented at the AIEE North Eastern District meeting, Springfield, Mass., May 3–5, 1939. Manuscript submitted February 17, 1939; made available for preprinting March 30, 1939.

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Complete segregation and analysis of the power requirements of various parts of the machines were seldom made.

Table I. Spinning-Frame Tests—Frame Data

Width—39 inches, length—51 feet
Number of spindles—360
Number operated during tests—348; others removed
Whorl diameter—1 1/8 inches
Gauge spindle—3 1/4 inches
Width tape—3/8 inch
Traverse—7 inches. With 2-inch and 2 1/4-inch ring traverse increased to 7 3/8 inches
Cylinder diameter—9 inches
Cylinder bearings—ball
Ring diameter—1 1/2 inches, 1 3/4 inches, 2 inches, 2 1/4 inches
Type ring—number 2 FDA
Traveler weight and number—number 2 flange—5/0–6 1/2 GR Bowen used on doffs 1–2–3. Doff number 5 used number 2 travelers. Doffs 6–7 use number 2 travelers. Two flange circle Al, style *RP*
Number yarn spun—33/1. Twist per inch—13
Doffs 5–6–7 20s yarn
Yarn spun—warp
Two-ply roving—3.50 hank
Type builder—combination set for warp
Thread board—traversing
Diameter front roll left side, 1 inch; diameter neck, 0.750 inch
Diameter front roll right side, 1 inch; diameter neck, 0.750 inch
Diameter middle roll left side, 7/8 inch; diameter neck, 0.592 inch
Diameter middle roll right side, 7/8 inch: diameter neck, 0.650 inch
Diameter back roll left side, 7/8 inch; diameter neck, 0.592 inch
Diameter back roll right side, 1 inch; diameter neck, 0.750 inch
Tape idler pulleys, ball bearing 2 3/4 inches diameter
Weight on front rolls four pounds
Gearing:
Cylinder..... 26 teeth
Jack.....112 teeth
Twist..... 44 teeth
Front roll.....100 teeth
Lay..... 51 teeth
Crown.....140 teeth
Top-roll gearing:
Back roll left side..... 33 teeth
Back roll right side..... 34 teeth
Middle roll left side..... 29 teeth
Middle roll right side.... 26 teeth
Intermediate each..... 40 teeth
Back roll (large) each....106 teeth
Top rolls cork—front and back
Weighting of top rolls:
Front = 22 pounds
Middle = 15 pounds
Back = 9 pounds

The power required to drive the machinery in the yarn spinning department usually represents approximately 50 per cent of the total power required for operating the mill, and power studies have usually been confined to this department because it has the greatest possibility of economic improvement.

In recent years many changes in spinning-machine designs have been made. Longer frames, larger spindles, bobbins capable of handling more yarn have been demanded by the textile manufacturer. These new designs and improved materials have made it possible to raise the operating speed, increase production, and reduce manufacturing and operating costs, necessitating more accurate power information.

The machinery manufacturers, the textile manufacturers, and the electric-motor manufacturers are vitally concerned with the problems of power requirements.

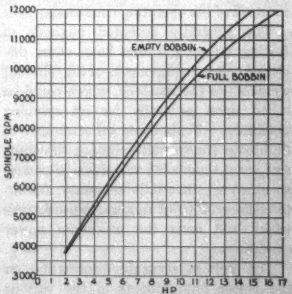


Figure 1. Spinning-frame tests—348 spindles, 1 1/2-inch-diameter ring

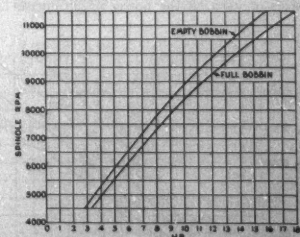


Figure 2. Spinning-frame tests—348 spindles, 1 3/4-inch-diameter ring

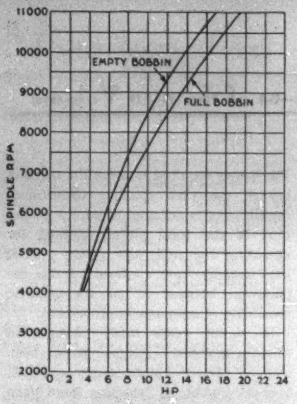


Figure 3. Spinning-frame tests—348 spindles, 2-inch-diameter ring

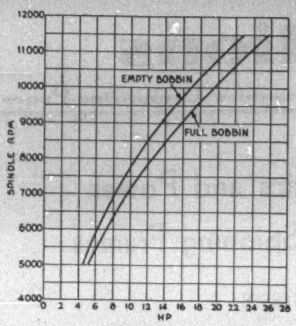


Figure 4. Spinning frame tests—348 spindles, 2 1/4-inch-diameter ring

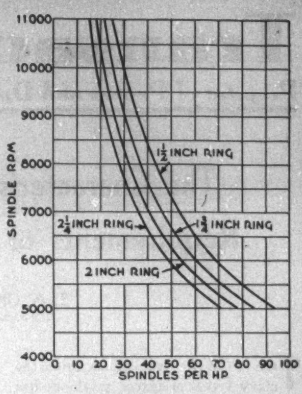


Figure 6. Spinning-frame tests—348 spindles

The machinery manufacturers are interested in producing the most efficient operating machines for the textile manufacturer. The textile manufacturer, in turn is interested in higher quality and higher production at minimum cost, while the motor manufacturer is interested in designing motors with characteristics which will suit the machine and meet all of the operating conditions.

The generally accepted methods of testing spinning frames have never disclosed power requirements of the different elements of the machine, which could be relied upon generally for all spinning machines. Tests made on a number of duplicate frames, all spinning the same size yarn, show wide variations in power; so much so, that it is necessary, for interchangeability of motors, to use ratings which will meet the maximum power conditions.

The lack of accurate information on the power requirements of the various elements of a spinning frame and the effect of changes in ring diameter, spindle speed, number of spindles, and different sizes of yarn on the power requirements has stressed the need for a careful analysis of the problem.

With this in mind, extensive power tests were made to establish the characteristic requirements and derive an empirical formula, if possible, which can be relied upon by the machinery manufacturers and the textile manufacturers to determine the horsepower required to drive the various types of spinning machines.

A modern 348-spindle frame with long-draft spinning system was selected for making the tests. The data in table I will show all the mechanical features of the frame.

Tests were carried on throughout the spinning cycle starting with a $1^1/_2$-inch-diameter ring and a medium-size spindle, followed by similar tests after changing the size of the ring to $1^3/_4$ inches diameter. The yarn spun during these tests was an average of 30s yarn, this being what may be classified as medium-count yarn in a textile mill.

On the completion of these power tests, a series of breakdown tests were carried on to determine the separate power requirements of the various elements of the frame, such as the cylinder only, cylinder and spindles; cylinder, spindles and front rolls; cylinder, spindle, full bobbins builder and no rolls.

Following these tests a heavier type spindle was installed on the frame with a two-inch-diameter ring and power readings taken throughout the spinning cycle.

After this test, the 2-inch-diameter rings were replaced by $2^1/_4$-inch-diameter rings and similar tests conducted followed by a set of breakdown tests. The yarn

Table II. Spinning-Frame Tests—Breakdown Tests

Small Spindles

Condition	Horse-power	Spindle RPM	
Cylinder, bare spindles, no steel rolls and no builder	2.0	4,115	
	2.9	5,488	
	4.0	6,860	
	6.2	9,227	
	8.6	11,234	
	12.5	13,618	
Cylinder, bare spindles, *front steel rolls* and no builder	2.6	4,061	
	5.2	7,063	
	6.3	8,090	
	9.0	10,348	
	11.0	11,869	
	13.5	13,139	
Cylinder, spindles, empty bobbins, no steel rolls, no builder	2.1	4,202	
	3.1	5,785	Empty bobbins, no appreciable power
	4.7	7,463	
	6.3	9,408	
	7.7	10,427	
	12.5	13,312	
Cylinder, spindles, empty bobbins, builder, no steel rolls	1.9	3,880	
	3.3	5,558	Builder, no appreciable power
	4.5	6,930	
	5.9	8,820	
	7.7	10,286	
	8.7	11,038	
	12.0	13,077	
Cylinder, bare spindles, builder, no steel rolls	2.1	4,163	
	3.5	5,864	
	4.9	7,212	
	5.8	8,294	
	7.5	9,862	
	13.0	13,800	
Cylinder, spindles, full bobbins and builder motion, no steel rolls	3.3	4,547	
	4.1	5,688	
	5.1	6,758	
	7.4	8,247	
	10.5	10,129	
	17.0	12,900	

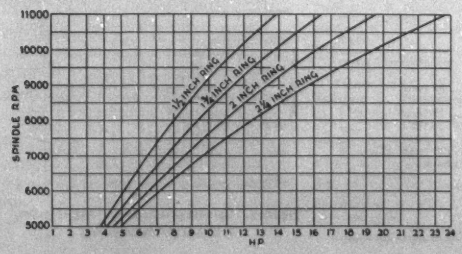


Figure 5. Spinning-frame tests — 348 spindles

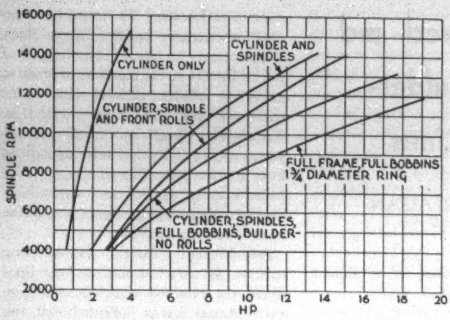


Figure 7. Spinning-frame tests—348 spindles, small spindles

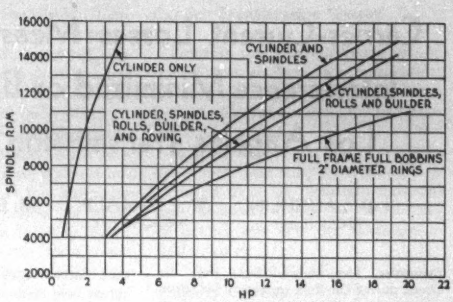


Figure 8. Spinning frame tests—348 spindles, large spindles

spun on the 2-inch and 2¼-inch rings was an average of 20s yarn.

During the spinning tests power readings were taken at the empty bobbin position at various spindle speeds and again at the full bobbin position with each size of ring.

The results of these power tests are shown on the accompanying curves for the four different ring diameters (figures 1, 2, 3, and 4).

As the most important data on these tests are the full-bobbin position, or maximum horsepower of the frame, the full-bobbin readings are plotted together and show very clearly the increase in power as the ring diameter increases, and also as the spindle speed is increased. It also shows that the ring diameter has a very important bearing on the power requirements of a spinning frame (figure 5). This is probably more clearly shown on the curve of spindles per horsepower when operating with different-diameter rings (figure 6).

The breakdown tests with either small or large spindles (figures 7 and 8) show definitely that the cylinder alone requires a very small percentage of the total power of the frame. The addition of spindles shows a very marked increase in the power required at various spindle speeds. The addition of the steel rolls does not materially increase the power. The addition of the full bobbins while not spinning shows a considerable increase in power which is due to windage and some small amount of friction. The full-power curve on these figures, which is the full-bobbin position while actually spinning yarn, shows a marked increase over the amount of power required by the cylinder, spindles, steel rolls, and full bobbins.

It is appreciated that the spindle speeds were increased beyond a point where practical spinning could be done, but this was necessary to establish the power requirements at high spindle speeds, and establish the characteristics of the frame.

The upper half of figure 9 is an analysis of the previous curves made and shows the characteristic increase in horsepower for various ring diameters plotted against the peripheral speed of the full bobbins in feet per minute. On this curve the solid lines are plotted from test data while the dotted lines are pro-

Table III. Spinning Frame Tests—Breakdown Tests

Large Spindles

Condition	Horse-power	Spindle RPM	
Cylinder only, no tapes	0.8	4,170	
	1.0	5,930	
	1.3	7,780	
	1.8	9,720	
	2.5	11,950	
	4.0	15,300	
Cylinder, bare spindles, no steel rolls, no builder	3.1	4,147	
	5.9	7,000	
	9.4	10,000	
	16.1	13,947	
	15.7	13,986	
Cylinder, bare spindles, no steel rolls, with builder	2.8	4,116	
	5.5	6,907	Builder, no appreciable power
	7.9	8,851	
	11.2	11,344	
	15.9	14,315	
Cylinder, bare spindles, front steel rolls, builder	3.3	4,061	
	5.5	6,287	
	9.3	9,023	
	13.9	11,908	
	16.6	13,429	
Cylinder, bare spindles, all steel rolls, builder	5.3	6,000	Back steel rolls, no appreciable power
	7.8	8,004	
	12.6	11,148	
	18.1	13,908	
Cylinder, bare spindles, all steel rolls, builder and roving	3.3	3,888	
	10.8	9,408	
	18.5	13,868	

Table IV. Spinning-Frame Tests—Analysis

Ring Size (Inches)		Revolutions per Minute for Peripheral Speeds of Feet per Minute								
		2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
1¼	Spindle speed	6,110	7,640	9,170	10,700	12,200	13,750	15,300	16,800	18,350
	Horsepower	5.25	7.5	10.0	13.2					
1¾	Spindle speed	5,310	6,370	7,640	8,910	10,200	11,460	12,730	14,000	15,300
	Horsepower	4.25	6.45	8.75	11.22	14.25				
2	Spindle speed	4,370	5,460	6,560	7,650	8,750	9,840	10,290	12,000	13,100
	Horsepower	5.37	7.72	10.15	12.8	15.75	19.3			
2¼	Spindle speed	3,490	4,500	5,400	6,300	7,200	8,100	9,000	9,890	10,800
	Horsepower			5.8	7.95	10.22	12.95	15.9	19.13	22.75

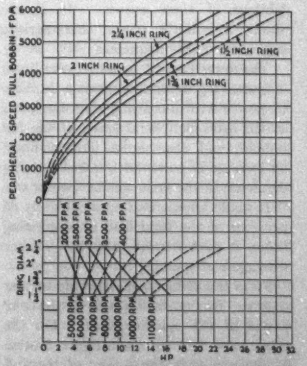


Figure 9. Spinning-frame tests—348 spindles, analysis

Carrier-Current Losses Measured and Interference Minimized on Boulder-Los Angeles Transmission Lines

J. D. LAUGHLIN ASSOCIATE AIEE W. E. PAKALA ASSOCIATE AIEE M. E. REAGAN MEMBER AIEE

Synopsis: Two unusual facts were disclosed during the field testing of the supervisory-control carrier-current channel on the 287-kv Boulder Dam-Los Angeles transmission lines. Carrier-current losses were much higher than calculations and previous experience had indicated. The interference from power equipment arcs could not be isolated by the use of resonant choke coils, requiring special circuit designs for satisfactory operation.

Background

SUPERVISORY CONTROL for the operation of the circuit breakers, disconnecting and ground switches of the Boulder Dam-Los Angeles transmission lines uses a carrier-current channel. These are the highest voltage lines operating in the United States and there was, therefore, no definite information available on the losses to be encountered; nor was there much knowledge of the magnitude of interference that might be caused by static, corona, or arcs from power equipment. Field tests have been made which have brought to light some interesting facts. It is the purpose of this article to record these experiences so that future applications of a similar nature may be facilitated.

Interference

Line noise, lightning, and arcs from the operation of oil circuit breakers, disconnecting, and grounding switches create carrier-frequency waves on the lines which interfere with the reception of normal working carrier signals.

The interference due to line noise is ever present and changes over wide limits. Dry dust or sand-laden air blowing across the line produces some interference. Rain increases the interference level. Increase in corona and lightning during wet weather produces the maximum interference. To overcome line-noise interference on the 287-kv lines, it is necessary to have a carrier signal of ten milliwatts at the receiver, in order to provide a sufficient ratio of signal to interference for satisfactory operation. The receiver sensitivity can then be adjusted to give no receiver relay operations from interference. This minimum power value may be applied to lower-voltage lines also since the gradients are of the same order of magnitude.

Interference from disconnecting switches is very serious on long lines where the received signal is relatively low. Measurements indicated that the interference from a disconnecting switch opening the charging current of a 287-kv breaker bushing 180 miles away was approximately ten times that produced by maximum line noise. It was found that interference from the high-voltage lines was a maximum at a receiver when it was raining at the receiver location.

The resonant choke coils do not hinder the transmission of arc interference. The arcs of each phase go out every half cycle and re-establish. As the arc again breaks down, the steep wave front (practically square) produces a large band of frequencies which are not stopped by the resonant choke coils.

On opening a disconnecting switch, the arc continues for more than one second with gradually increasing interference. Its peak value occurs just before the arc is extinguished. The interference is greatest when the second disconnecting switch is opened on the end of an energized section since the capacity of the line raises the voltage at that point. The first disconnecting switch, in opening, only opens a parallel path with the last one and, therefore, results in opening a lower voltage arc. On closing a disconnect, the interference is of a lower level and shorter duration.

Oil circuit breakers when opening and closing any loads or line-charging current create the same magnitude of interference but last a very short time [two or three cycles (60)].

The interference from ground-switch operation is low in magnitude, being that of grounding the static charge stored on the de-energized line conductors. It is a maximum when grounding a section which is paralleling an energized line.

Effect of Interference on Signaling Codes

Practically all supervisory-control systems depend on a code of pulses for selection, indication, and operation. To dis-

Paper 39-93, recommended by the AIEE committee on automatic stations, and presented at the AIEE North Eastern District meeting, Springfield, Mass., May 3-5, 1939, and at the combined summer and Pacific Coast convention, San Francisco, Calif., June 26-30, 1939. Manuscript submitted October 22, 1938; made available for preprinting March 23, 1939.

J. D. LAUGHLIN is junior electrical engineer, Bureau of Power and Light, City of Los Angeles, Calif.; W. E. PAKALA is engineer, and M. E. REAGAN is section engineer in the switchgear engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

jections of these curves. It clearly shows a uniform power characteristic regardless of ring diameters.

The lower part of figure 9 (solid lines) is interesting because it shows a decrease in power with increasing ring diameters at the same peripheral speed of the full bobbin, and also shows (dotted lines) an increase in power with increasing ring diameters at the same spindle speeds.

It would appear that approximately 65 per cent of the total load of a spinning frame is pure friction, and the balance windage and spinning.

From test data taken, it would appear that the friction load varies as the 1.42 power of the spindle speed. On the other hand test curves in figure 5 seem to indicate that the power of the full frame while spinning varies as the 1.68 power of the speed with a $1^1/_2$-inch ring, the 1.765 power with a $1^3/_4$-inch ring, the 1.865 power with a 2-inch ring, and the 1.99 power with a $2^1/_4$-inch ring.

To use this, one must have some definite power reading on the frame in question, but since this is not always available it would be much more satisfactory to have a formula which is based on spindle speed, ring diameter, and a constant from which the power of any frame may be calculated. For example the formula:

$$\text{Horsepower per spindle} = 0.000284 \times R^{1.42} \left(\frac{\text{rpm}}{1{,}000}\right)^{1.868}$$

seems to hold fairly well for the test data thus far obtained, but it may be necessary to modify this formula or introduce another constant to make it apply to larger ring diameters and twisting operations.

tinguish one code from another, the number and timing of the impulses must be of a definite character.

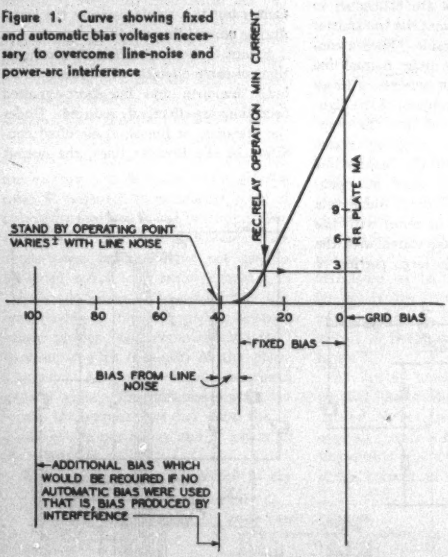
The effect of arc interference on the codes varies with the type of operation and the device being operated. First, consider operations by the dispatcher. During the selection and check, no operations of power equipment occur and there is no interference. The dispatcher then initiates the operation control code to start the remote apparatus to close or open, as the case may be. The interference starts here. On closing or tripping a circuit breaker, there is a short arc of one to three cycles depending on the speed of the breaker. To the carrier equipment this represents a short pulse. The breaker auxiliary switches, which initiate the supervision indication, operate about the same time. Should the interference pulse be permitted to operate the receiver relay, an extra pulse would be added to the indication code and thus cause the supervisory control equipment to lock-out. It is then necessary for the dispatcher to reset the equipment before the new indication is reported.

For disconnecting switches, the operation is different for opening and closing in the length of arcing time and the time when it occurs with respect to the supervisory code. In opening the switch, enough time elapses between the operation of the pallet switches which initiate the signal and the start of the arc to get the new signals properly registered. In closing, the arcing time is shorter and is complete before the pallet switches initiate the signal to indicate the position.

Automatic or manual operation of the equipment at the substation sends in a selecting code to the office, which is immediately followed by the indication code. With circuit breakers, the arcing is completed before the signalling begins, but may add onto the start of the selection code if the first pulse of the selection code occurs within 0.05 second of the arc pulse. In opening a disconnect from the dispatching office at Boulder, the signal is finished before the arc starts, while in closing the arcing is complete before the signalling begins.

It is advisable, therefore, to make the receivers inoperative when the arcs are occurring. This is done by rectifying the output of a separately tuned circuit (excited by components in the interference-signal of some frequency other than the frequency of carrier operation and preferably lower) and using it as a heavy negative bias on the receiver tubes. See figure 1. Thus, methods of overcoming the interference are (1) make the interference miss the time of signalling and (2) make the receiver less sensitive during the interference.

Figure 1. Curve showing fixed and automatic bias voltages necessary to overcome line-noise and power-arc interference



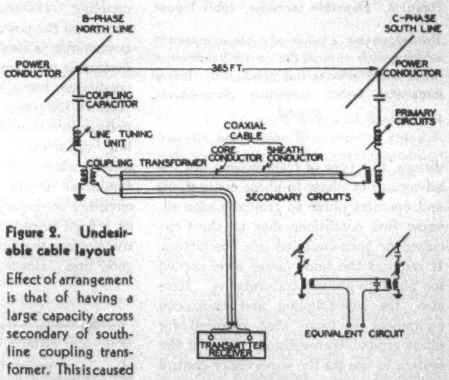


Figure 2. Undesirable cable layout

Effect of arrangement is that of having a large capacity across secondary of south-line coupling transformer. This is caused by the high capacity of sheath to ground of secondary cable, with abnormal line conditions, the resulting unbalance can create large carrier transmission losses

Carrier Transmission Losses

Probably the most interesting part of the field tests concerned the measurement and segregation of carrier transmission losses under various combinations of line sections in service.

In order to segregate the transmission losses into their component parts, it is advisable to divide them into their two main divisions. These are the primary or line circuits and the secondary or station losses.

Primary Circuits

High-voltage capacitors with a series tuning inductance and a coupling transformer are used to connect the carrier transmitters and receivers to the line. Paralleled tuned resonant choke coils are necessary in isolating the channel from spur lines and other paralleling circuits. These, with the line conductors are known as "primary" circuits and may be segregated into phase-ground, phase-phase, and phase-phase-ground connections.

Phase-to-ground transmission requires, for the same reliability, the most power per unit distance. It is useful for short distances (30 miles or so) at low-power (15 to 30 watts) inputs. The connection has the advantage of using the minimum of coupling capacitors, line tuning units, and resonant choke coils.

Phase-to-phase transmission will give about two to over three times the power per unit distance as compared to the phase-ground connection. (See appendix where the ratio was 3.25.) It has the lowest losses for channels on single-tower lines. On double-tower lines where a phase wire of each circuit is used, the phase-to-phase loss may not be much less

than phase to ground. The lower losses result in higher received carrier power. Also, the amount of coupling equipment is roughly twice that required for phase-to-ground connections.

Phase-to-phase-to-ground transmission is the most reliable. Under normal conditions, this type of transmission has the advantage of phase-to-phase connections and operates phase to ground under adverse line conditions due to short-circuited or open-circuited line conductors. It requires the same power level needed for phase-to-ground transmission. Here also, the line-coupling and choke-coil equipment is twice that required for phase-ground transmission. This is the system in use on the supervisory-control system controlling the various switching devices on the Boulder Dam-Los Angeles twin-circuit transmission lines.

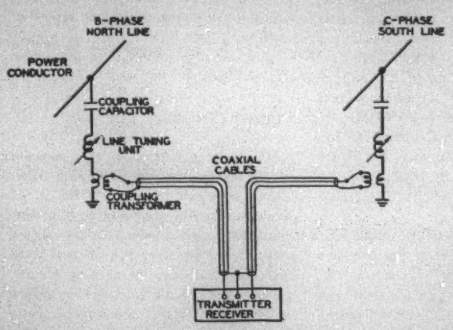


Figure 3. Desirable secondary cable layout

This layout gives a balanced cable arrangement which greatly reduces the carrier transmission losses under adverse line conditions. It is a three-wire system operating phase-phase-ground

Secondary Circuits

The secondary circuits consist of the secondary windings of the coupling transformers, cable circuits, and the primary windings of the transmitter output as well as the receiver input transformer. The voltage ratio of the coupling transformer is chosen to match the impedance characteristic of the high-frequency cable. Low-loss coaxial cable is available for such service and was used on the Boulder lines. The cable used has approximately 35 times the high-frequency losses of the phase-to-phase primary circuit channel of the same length.

Special attention must be paid to the type and arrangement of the connecting cable. It can be the source of tremendous losses under certain adverse line conditions if not properly connected. With the cable arrangement shown in figure 2, the secondary windings of the coupling transformers are connected in series and the power from the transmitter is sent over a single cable. Such a connection is satisfactory under normal line conditions, but a large increase in losses occurs if the power conductor of the high-voltage line should break near the coupling capacitors. The coupling transformer associated with the broken line conductor would then have an open-circuited secondary winding, which acts as a high impedance in series with the transformer winding associated with the good line. Hence, the large portion of the transmitted voltage appears across the transformer where it can do no good. The Boulder line tests showed that, with the line broken, the loss is 14 decibels greater than under normal conditions with the average distances as shown. The cross-tie portion of the cable also may approach parallel resonance (see equivalent circuit of figure 2) with the inductance of the coupling transformer. Resistors could be used to parallel the coupling-transformer primary-circuit winding and thus reduce the impedance of the open-circuited coupling transformer but this would increase the losses during normal line conditions.

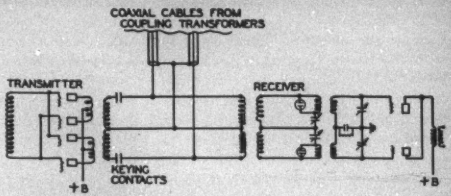


Figure 4. Schematic arrangement of connections of the secondary coaxial cables to the transmitter and receiver circuits

Figure 3 shows the desirable connections of cable circuits. The losses under both line-open and line-short-circuited conditions are effectively reduced. Under the line-open or line-short-circuited condition of the Boulder lines, the output

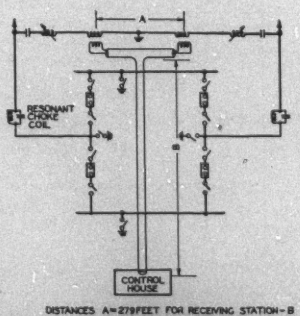


Figure 5. Boulder-Los Angeles lines—terminal stations

Layout of stations—single-line diagram. Shows lengths of high-frequency cable necessary to connect indoor transmitter-receivers to lines

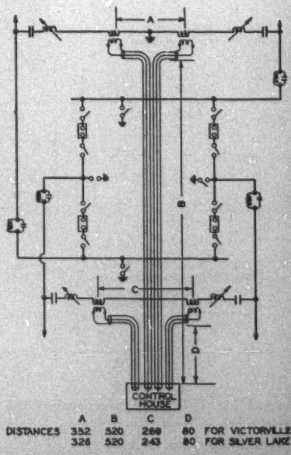


Figure 6. Boulder-Los Angeles lines—intermediate switching stations—layout of stations

Single-line diagram shows lengths of high-frequency cable necessary to connect indoor transmitter-receivers to lines

power is reduced only one-half, representing an additional loss of 3 decibels instead of 14 measured with the cable arrangement of figure 2. Each line of the double phase-ground transmission circuit (see figure 4) is independent of the other except for slight changes in the regulation of the transmitter, since each half of the circuit operates independent of the other but from a common power supply. The input circuits into the receiver are also divided into two transformers and input tubes, so that changes on one line will not be seriously reflected into the other or affect the tuning on the working half.

The Boulder Line Characteristics

In measuring the carrier transmission losses on the lines using cable connections of figure 2 at the intermediate stations and of figure 3 at the end stations, some interesting loss characteristics were recorded. (See figures 5, 6, 7, and 8.) First, with the high-voltage lines continuous throughout but with no by-passes in the circuit, the loss at 60 kilocycles was 20 decibels. This loss was measured from end to end and the value 3.33 decibels in figure 8*A* was obtained by dividing the total loss by six, it being assumed that the loss in each section is the same. The lines are approximately 270 miles in length and the calculated loss is only 4.43 decibels. This gives a ratio of measured to calculated losses of approximately five to one (see appendix). Previous tests reported[1] on lower-voltage single-tower systems have not greatly exceeded a 2.5 to 1 ratio of actual to calculated losses. The additional loss may be due to the large spacing between power phases (approximately 265 feet) as compared to distances of the phase conductors to ground and the overhead ground wires. The distance is great because the carrier channel uses the *B* phase of the north line and *C* phase of the south line.

With the by-passes connected in the circuit and the lines energized throughout, the over-all carrier transmission loss increased to 24 decibels. Since the line measured 20 decibels the additional loss of 4 decibels divided by 12, the number of coupling units, gives 0.33 decibels as the equivalent loss per coupling unit. See figure 8*B*. The loss per by-pass was calculated to be 3 decibels. The difference is due to coupling to the other unchoked phases, which forms a parallel circuit to the by-pass equipment. (See figure 9.)

As circuit breakers are opened, the parallel paths through the other unchoked phases are interrupted and the over-all losses increase. The unused phase wires would not affect transmission if the current in them were zero. The transmission line transpositions are ineffective at 60 kilocycles because of the unbalanced loadings. An unbalance occurs because the terminating impedances to ground on the unused phases are not the same at 60 kilocycles since choke coils used in these phases are tuned to different frequencies. This unbalance makes the by-pass losses lower (see figure 8*C*) on the closed line side than on the open breaker side where all transmission is through the by-pass equipment. Where a phase wire of each line is used, the opening of one line only increases the loss to 32 decibels. Dividing this increase of 8 decibels among the four south line by-passes affected gives 2.33 decibels total loss per coupling unit. The total loss per by-pass (four coupling units) is now increased to 5.33 decibels.

When breakers of both lines are opened, both sides of the transmission channel are affected, and the loss increases by another 8 decibels. This additional loss is divided by four and the result added to

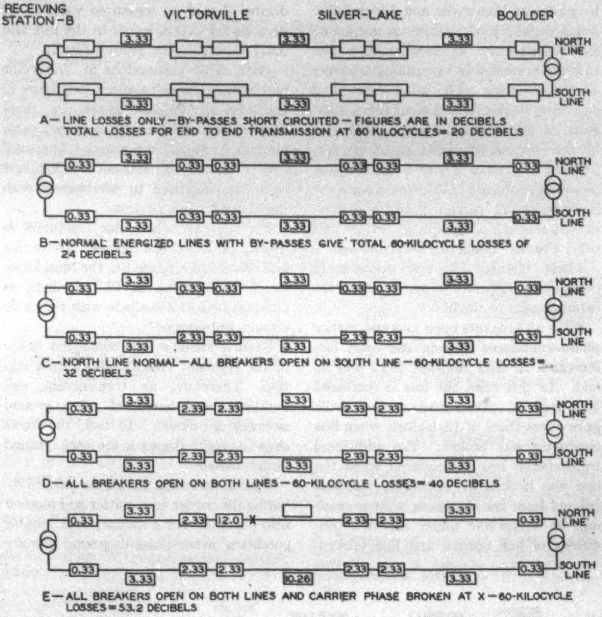

RECEIVING STATION-B
VICTORVILLE
SILVER-LAKE
BOULDER
NORTH LINE
SOUTH LINE
A—LINE LOSSES ONLY—BY-PASSES SHORT CIRCUITED—FIGURES ARE IN DECIBELS
TOTAL LOSSES FOR END TO END TRANSMISSION AT 60 KILOCYCLES=20 DECIBELS
B—NORMAL ENERGIZED LINES WITH BY-PASSES GIVE TOTAL 60-KILOCYCLE LOSSES OF 24 DECIBELS
C—NORTH LINE NORMAL—ALL BREAKERS OPEN ON SOUTH LINE—60-KILOCYCLE LOSSES=32 DECIBELS
D—ALL BREAKERS OPEN ON BOTH LINES—60-KILOCYCLE LOSSES=40 DECIBELS
E—ALL BREAKERS OPEN ON BOTH LINES AND CARRIER PHASE BROKEN AT X—60-KILOCYCLE LOSSES=53.2 DECIBELS

Figure 8. Schematic layout of Boulder-Los Angeles transmission lines showing approximate distribution of carrier-current transmission losses under various line connections

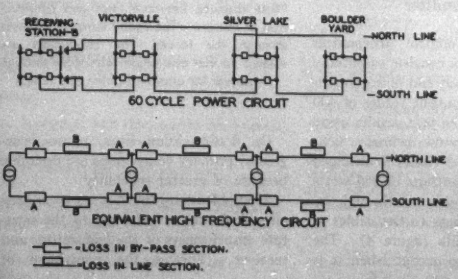


Figure 7. Single-line power and high-frequency circuits—Boulder - Los Angeles transmission line

1. For all numbered references, see list at end of paper.

by-passes at Victorville and Silver Lake. Tests showed that changes in output at Los Angeles and at Boulder were not changed appreciably by opening breakers at these points. The total loss at a switching station is 9.32 (four times 2.33) with all line breakers open. With one breaker opened at either switching station, an additional loss of 4 decibels was measured. Figure 8*D* gives losses for lines when all carrier power is transmitted through all coupling devices and cable circuits connecting these devices.

These changes do not appreciably change the impedance matching of the cable circuits to the line.

With all breakers open and one carrier phase conductor broken, the total loss increases to 53.2 decibels from end to end. In this case, the loss is increased 13.2 decibels. Tests made at Victorville gave a loss there of 12 decibels when line conductor was broken. The additional transmission loss encountered when the line was broken at Victorville was calculated from the change in voltage readings at Victorville under the two conditions of line normal and line broken. decibel (based on measured value of 20 decibels for 270 miles) is in the line and 0.077 decibel in the ground circuit.

With cable connections at Victorville and Silver Lake unbalanced (see figure 2) the over-all by-pass losses are three decibels higher than with balanced cable circuits as shown in figure 3. The total loss is 37 decibels, with all line breakers open, as compared to 40 decibels with unbalanced cable circuits.

For the case where line conductor is broken on north line between Victorville and Silver Lake, figure 8*E*, the total losses are 5 decibels less or 48.2 decibels, as compared to 53.2 decibels with the cable circuits unbalanced.

Ground switches are connected inside of the resonant choke coils at each station. Therefore, no transmission difficulties are encountered when ground switches are closed. In fact, the losses show a slight decrease for each ground switch closed.

Special attention should be paid to dividing the carrier transmitter and receiver into parts in such a manner that trouble condition on one phase-to-ground primary being keyed by the supervisory control equipment.

The Receiver

A heterodyne receiver is used with a beat frequency of 600 cycles or more from zero beat. The input, for double-circuit reception, consists of two input transformers (see figure 4) with series tuned circuits on the secondary side and parallel tuned circuits on grids of the input tubes. The coupling between the two sides of the receiver input circuit is low. Thus grounds or open line conductors do not change the tuning on the unfaulted side of the circuit.

Conclusions

To overcome line noise, the minimum power received for satisfactory operation at any point should be ten milliwatts above line noise level.

For greater interferences, such as that caused by arcs, more received power is necessary or special means are required to prevent altering of coded signals.

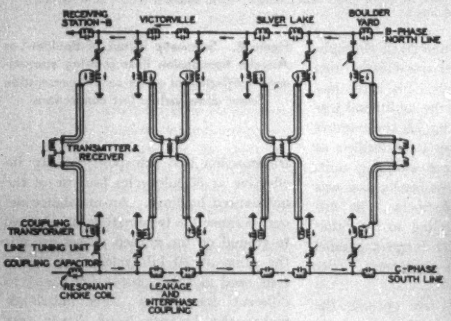


Figure 9. Carrier-current circuit

Primary and secondary arrows show instantaneous current values throughout system. Proper phasing is necessary to get leakage and interphase coupling current to add in phase with current through by-pass

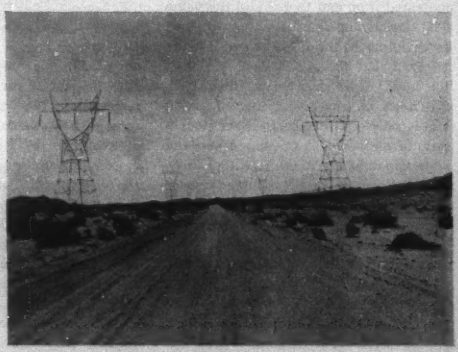


Figure 10. View of double tower construction used for approximately 78 per cent of line length

Note distance between lines and construction of towers. The center conductor passes through the tower. The conductors are rotated so that one phase wire goes through the tower for one-third of the line length

(This is shown in figure 8*E*.) Neglecting small increase in losses at Silver Lake, (measurements showed that opening line at Victorville does not appreciably change losses at Silver Lake) the line-to-ground loss for the 90 miles from Victorville to Silver Lake is 10.25 decibels. The loss per mile phase to ground is 0.114 decibel. Of this value 0.037 circuit will not materially affect the operation of the other half.

The Carrier Transmitter

The supervisory-control transmitter on the Boulder lines consists essentially of an oscillator, buffer, and power amplifier with a normal output rating of 400 watts. To obtain the best results using the phase-phase-ground primary connections, the amplifier circuit is arranged with two push-pull outputs of 200 watts each. These are connected through independent transformers to the cables of the secondary circuits (figure 4). The plate current is zero except when it is

On double-circuit lines, phase-phase-ground primary connections are desirable because of greater reliability.

The cable arrangement of the secondary circuits should be balanced to the separate transformers of the transmitter and receiver. This is the equivalent of

two independent phase-ground systems.

High-frequency losses over the 287-kv Boulder-Los Angeles power lines measured approximately five times those calculated, using the present accepted methods for such calculations (see appendix). Previously reported tests gave a maximum of approximately 2.5 times. It is apparent that changes in the present working formulas will be necessary.

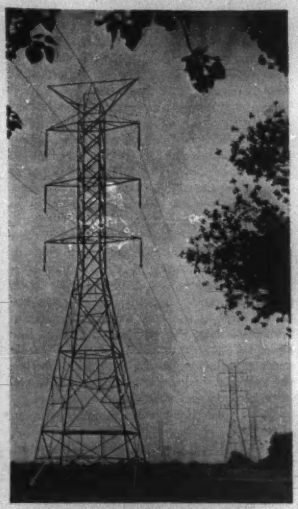


Figure 11. View of single-tower construction used for approximately 22 per cent of line length

The phase wires of the two lines are relatively close with none passing through the towers

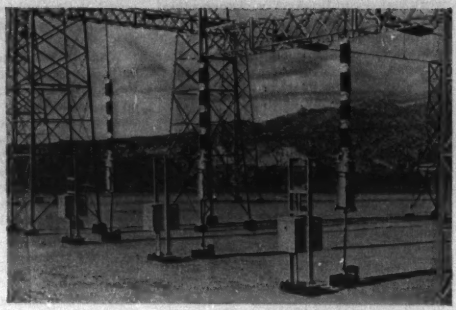


Figure 12. One corner of an intermediate switchyard showing outdoor line-tuning units. Underground coaxial cables connect the carrier circuits to the indoor transmitter-receiver sets

Appendix

Calculations of Line Losses

The high-frequency resistance for tubular conductors as given in Bureau of Standards Circular No. 74, page 301 is

$$\frac{R_{ac}}{R_{dc}} = 10V2t(0.01071Vf) = 0.1514tVf \qquad (1)$$

where

t = conductor wall thickness in centimeters
f = frequency in cycles per second
$\frac{R_{ac}}{R_{dc}}$ = ratio of a-c to d-c resistance

At 60 kilocycles, and wall thickness of 0.278 centimeters.

$$\frac{R_{ac}}{R_{dc}} = 0.1514 \times 0.278V60{,}000 = 10.32$$

The d-c resistance of conductor (512,000 circular mils) is 0.22 ohms per loop mile. Hence the 60-kilocycle resistance for conductor is

$$R_{ac} = 10.32 \times 0.22 = 2.27 \text{ ohms per loop mile}$$

The approximate formula for the real part of the attenuation constant is as follows:

$$a = \frac{R}{2Z_0} + \frac{CZ_0}{2} \qquad (2)$$

for the real part of the propagation constant where

R = resistance in ohms
G = leakage conductance in ohms
Z_1 = surge impedance = 600 ohms phase to phase
a = attenuation constant

For high-voltage open-wire lines $G = 0$ and (2) reduces to

$$a = \frac{R}{2Z_0} \qquad (3)$$

In terms of current, for long lines

$$I_x = I_0 e^{-ax}$$

$$\text{DB} = 10 \log_{10} \frac{I_0^2}{I_0^2 e^{-2ax}} = 10 \log_{10} e^{2ax}$$

$$= 20ax(0.4343) = 8.686ax$$

Substituting from (3)

$$\text{DB} = \frac{8.686R}{2Z_0} = \frac{4.343R}{Z_0} \text{ per unit length} \qquad (4)$$

In this case the a-c resistance is 2.27 ohms per loop mile.

$$\text{DB} = \frac{4.343 \times 2.27}{600} = 0.0164 \text{ per loop mile}$$

For 270 miles of line, the loss as calculated is 4.43 decibels.

When transmitting phase to ground, the calculated losses are as follows:

The ground circuit can be along a copper circuit consisting of two quarter-inch-diameter copper wires for which the 60,000-cycle resistance is 2.55 ohms per mile as calculated by Bureau of Standards formulas. For this value of resistance the loss is

$$\text{DB} = \frac{4.343 \times 2.55}{300} = 0.037 \text{ per mile}$$

In this case $Z_0 = 300$ ohms as measured. The total line-to-ground transmission loss is $0.0164 + 0.037 = 0.0534$ decibels per mile.

References

1. C. A. Boddie. IRE *Transactions*, June 1927.
2. A Self-Checking System of Supervisory Control, M. E. Reagan. AIEE Transactions, volume 57, 1938, pages 600–05 (October section).
3. Symposium on Operation of the Boulder Dam Transmission Line—Carrier Current Equipment, J. D. Laughlin. AIEE Transactions, volume 58, 1939, pages 147–51 (April section).

Discussion

W. A. Lewis (Cornell University, Ithaca, N. Y.): There are two points in connection with this paper that I would like to augment.

The discussion points out the serious effects on the operation of the carrier-current supervisory equipment caused by arcing at the opening and closing of disconnecting switches and circuit breakers. Those engineers who are concerned with the operation of carrier-current relaying equipment may have some fears regarding the effects of similar arcing on the performance of carrier-current relaying equipment. However, the large number of satisfactory installations of carrier-current relaying suggests that such fears are not warranted. Tests made a number of years ago perhaps indicate why this is so. It was found at that time in tests made at low voltage that a flaming arc in air did not produce appreciable amounts of high-frequency transients in the carrier-frequency range, whereas spark discharges, as are obtained by the opening of disconnecting switches which open only a small amount of charging current, and also arcs in circuit breakers which are very quickly extinguished both produce large amounts of high-frequency energy which may operate the carrier-current receivers of the relaying equipment. Fortunately, the necessity for the receiver responding only to the carrier-current energy transmitted by the transmitter at the opposite end of the line is only critical for the duration of the fault, and after proper circuit breakers have been selected, and have started to open, it is unimportant that the carrier-current receiver may be momentarily energized. In the

event that circuit breakers or disconnecting switches are opening at the moment a fault occurs on an adjacent line section, it is conceivable that the carrier energy from the operation of the circuit breaker or disconnecting switch may interfere with the relay operation, but in any event it is probable that the most serious effect will be a short delay in the operation of the line relays.

The method of computing the transmission loss is described in the paper, and it may be seen that the only losses considered are the high-frequency copper losses in the copper conductors actually involved in the circuit. From the tests, it is evident that there are additional losses which are not taken into account by this method of calculation. From the physical standpoint the supervisory-control circuit consists of a single-turn loop, one side of which is the *B*-phase conductor of the north line, and the other side is the *C*-phase conductor of the south line, separated by 365 feet from the other side of the loop. It may readily be visualized that this loop forms the primary circuit of an air-core transformer, the secondary of which consists of eddy-current paths in the earth immediately below the carrier transmission circuit. It is to be expected that eddy currents would be produced in the earth, and their losses would appear as transmission losses to the carrier-current circuit. Also, there will be some radiation, and some current induced in the other neighboring conductors. All of these losses will add to the conductor copper loss in the carrier channel. For the calculation of ground-return circuits at power frequencies, the formulas developed by J. R. Carson, or some modification of them, have been used with considerable success. Investigation of the underlying premises indicates that theoretically, at least, these formulas are applicable to the carrier frequencies in the range covered by this installation. It would be extremely interesting, therefore, to calculate the losses of this circuit by means of the Carson formulas, and determine if these formulas give an adequate representation of the losses. In any event it is to be expected that such calculations would give a much closer approach than is obtained when only the conductor copper losses are included.

Fred B. Doolittle (Southern California Edison Company, Los Angeles): Appreciation is due the authors for making available the information contained in their paper entitled "Carrier Current Losses Measured and Interference Minimized on Boulder-Los Angeles Transmission Lines". It is to be hoped that further study will reveal the reason for the five-to-one ratio between measured and calculated transmission losses.

While the secondary circuits used by the authors were different than those used by the Southern California Edison Company on the application of carrier-current protection to the 96-mile Gould-Magunden 220-kv transmission line and while the line construction is also different it would hardly seem that these factors could account entirely for the discrepancy which appears to exist between phase-phase and phase-ground transmission losses on the two lines. The received power phase to phase being 3.25 times that phase to ground as reported for the Boulder line is a much greater difference than found on the Gould-Magunden line. Tests on the latter in 1932 indicated phase-to-ground transmission was about 70 per cent as efficient as phase-to-phase.

The ingenious scheme described in the paper for blocking the receiver during the occurrence of high-voltage switching interference is of course well suited to the purpose for which it is used. However, it should not be used where the carrier signal is for the purpose of preventing the operation of tripping relays for transmission line protection. When, in 1932, it was observed that switching arcs on the Edison 220-kv system produced interference of sufficient magnitude to flashover all of the protective gaps associated with the carrier-current coupling equipment it was first thought that it would be impracticable to use sufficient carrier-current power to override interference of such magnitude. However, further experimentation demonstrated that such was not the case and that a $7^1/_2$-watt carrier-current transmitter over a 30-mile line could produce three or four times as much average detector plate current in a properly biased receiver as was produced by the interference created by operation of a 220-kv disconnecting switch. This fact made possible the interlocking type of carrier-current protection which was placed in service on the East Gould-Laguna Bell 220-kv line in April 1933.

While use was made of the fact that comparatively small amounts of carrier power would override violent interference, the reason therefor was not definitely proved until some months later when, by means of a cathode-ray oscilloscope, the wave form of the detector grid voltage was viewed. This wave form under switching interference was that of a damped oscillation in the resonant circuit of the receiver produced by shock excitation, twice each cycle of the power frequency when the instantaneous power voltage reached sufficient magnitude to jump the switch gap. The maximum magnitude of the damped oscillation could be controlled by the setting of the protective gaps in the carrier-current coupling circuit. Of course the continuous wave received from the remote transmitter was not damped and produced a higher average detector grid voltage than the series of damped oscillations caused by the interference.

J. D. Laughlin, W. E. Pakala, and M. E. Reagan: Doctor W. A. Lewis points out that experience has shown that interference from breakers and disconnecting switches does not produce faulty operation on carrier-current relaying systems. It is fortunate that interference power level in the carrier-frequency spectrum is sufficiently low to enable us to use less than 50 watts of power for carrier-current relaying and receiver sensitivities so low that interference has no effect on the receiver relays. Interference, however, should be considered, and too low carrier power levels should not be used. For carrier loss calculations it has been general procedure to calculate copper losses as in the paper, and then use factors obtained by experience on high-frequency transmission over power lines to obtain line losses for the design of equipment. We have made calculations taking into consideration the losses in the ground circuit and have obtained loss value of 30.4 decibels (line only) for earth resistivity of ten ohms per meter cube.

Fred B. Doolittle has brought up a point which was not made sufficiently clear in the paper. One phase-to-ground loss was measured as 26 decibels and the phase-to-phase loss as 20 decibels. The statement made in the paper that the phase-to-ground loss is 3.25 times the phase-to-phase loss is based on a calculated value, assuming that all ground current is concentrated in the counterpoise wires.

The effect of interference from switching on the detector plate meter and receiver relay is not, as pointed out by Mr. Doolittle, as serious as would be expected from observation of breakdown of the protective gap. High crest voltages of only a few microseconds duration have no effect on the receiver relay, which is relatively a low device connected in series with a vacuum tube which can act as a current-limiting device. However, interference of long duration, such as from the 287-kv disconnecting switches, will pick up the receiver relays unless some means is provided to desensitize the receiver during interference time. The system described in the paper requires carrier transmission for 270 miles at the time interference is transmitted for much shorter distances.

Hydrogen-Cooled Turbine Generators

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ONE of the most radical innovations in the design of electrical machinery in recent years has been the adoption of hydrogen cooling for large turbine generators. Now that a number of the large hydrogen-cooled units are in operation, it would seem timely to review the experience gained in building and operating this new-type equipment.

The developments leading up to the design of the present large machines may be summarized briefly as follows. In 1923, Max Schuler of Germany took out an American patent covering the cooling of rotating electrical machines with hydrogen gas. The company with which the writers are associated took out a license under this patent in 1924 and began development work on a suitable sealing device to prevent escape of gas along the shafts of the machine where they come out of the gas-tight housing. The shaft sealing glands, as they shall be referred to hereafter, were developed in essentially their present form in 1926. Work was then started on a 7,500-kva 3,600-rpm turbine generator with hydrogen cooling, and this was built and tested in 1928. A second machine of the same size was built and tested in 1930. The results of these tests are covered in a previous paper by one of the authors.[6]

During the years 1930 to 1936, no commercial applications of this new method of ventilating machines were made largely because of the small number of machines sold during that time. Early in 1936, there developed a considerable demand for large 3,600-rpm high-pressure topping units to be used to modernize old stations. The increased output from a given size machine with hydrogen cooling permitted units to be built in ratings up to 50,000 kw with the materials and experience then available. Since 1936, over 580,000 kva of hydrogen-cooled turbine generators have been sold representing 11 units, the largest of which is rated 81,250 kva at 80 per cent power factor at 3,600 rpm. One unit rated 75,000 kva at 80 per cent power factor at 1,800 rpm has been in operation for some time. All the other units are designed for a speed of 3,600 rpm. The smallest unit is rated 37,500 kva at 80 per cent power factor at 3,600 rpm.

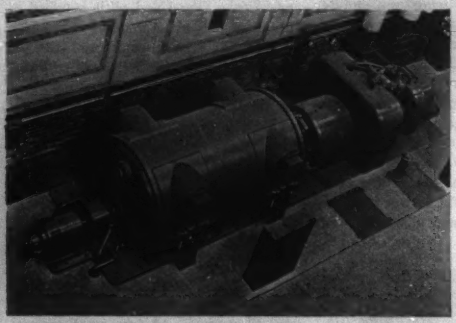

Figure 1. A 53,000-kw hydrogen-cooled generator and turbine installed at Waterside station, New York City

Advantages of Hydrogen as a Cooling Medium

The advantages of hydrogen cooling have been covered fully in a number of papers. It is sufficient, therefore, only to state briefly the principal points here, as follows:

1. Reduced windage, friction, and ventilating losses, because of the low density of the hydrogen gas. The ventilating losses are proportional to the gas density. Full load efficiency of the generator may be 0.6 per cent or more higher than for the corresponding air-cooled machine.

2. Increased output per unit volume of active material, because of the high heat storage capacity and thermal conductivity, and heat transfer coefficients of hydrogen. This advantage of hydrogen cooling makes it possible to build turbine generators for higher ratings than are possible with air cooling.

3. Reduced maintenance expense, because of the freedom from dirt and moisture.

4. Increased life of the insulation on the stator winding, because of the absence of oxygen and moisture in the presence of corona.

5. Reduced windage noise, because of the low density of the gas.

Description of Hydrogen-Cooled Generator

Hydrogen-cooled generators are designed so as to be "explosion-safe"; that is, all equipment is built to withstand a hydrogen explosion without damaging life or property. During normal operating procedure, an explosive mixture of hydrogen and air will not exist in the generator; however, in order to take care of faulty operation or unforeseen conditions, a suitable control and signal system is provided to warn when operation is approaching dangerous conditions. The operating hazard of a hydrogen-cooled generator is no greater than that of an air-cooled machine. Hydrogen is usually associated with dangerous explosions, but it is important to note that oxygen is required in considerable quantity before hydrogen will burn; explosive mixtures of air and hydrogen contain from 5 to 70 per cent hydrogen by volume, various authorities differing a small amount on these figures. The purity of the hydrogen in the generator is maintained above 95 per cent hydrogen, well above the upper explosive limit. The operating procedure together with the control system make a hydrogen explosion a remote possibility.

The construction features of a hydrogen-cooled generator are shown in figures 2 and 3. The generator frame and end domes are fabricated from steel plate which is rolled and welded to form the required shapes; the generator shell being cylindrical and the end heads being dome shaped as these shapes will best withstand the high internal pressure which would result from an explosion. On the basis of the most favorable mixture for an explosion, the pressure developed inside the machine enclosure

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6. For all numbered references, see list at end of paper.

would not exceed one-half the maximum theoretical value, because of the large heat-storage capacity of the machine and the exposed surfaces of the large mass of the parts of the machine. Analysis and experience indicate that the maximum actual explosion pressure will not exceed 85 pounds per square inch; consequently, it has become accepted practice to design the housings of hydrogen-cooled machines to withstand an internal pressure of 100 pounds per square inch without failure. Frame welds are tested individually for gas leaks and the complete generator frame and end domes are tested for leaks with water pressure at 75 pounds per square inch. The joints in the generator frame and end head assembly which must be gas-tight are made with suitable gaskets and cement.

Armature laminations are built into the frame after the water pressure test. The stator laminations are varnished and baked, and then the stator coils are installed in the stator slots, the coils being transposed and stranded to reduce eddy currents to a minimum. The generator main leads are brought out through gas-tight capacitor-type bushings which are bolted to the generator frame. Nine armature temperature detectors are located in the armature windings, and four temperature detectors are located in the gas passages, one at the inlet and outlet of each gas cooler.

The generator rotor is made from a single forging in which slots are machined to receive the rotor winding. Ventilating passages are provided under the coil slots and in the end windings to secure efficient ventilation of the rotor. The rotor end turns are supported by coil retaining rings which are shrunk on the rotor body.

Hydrogen-cooled generators are equipped with finned-tube-type gas coolers, located above or below the stator core; in either case, the gas coolers are located so that the tubes run crosswise in the generator frame. The nozzle end of the gas cooler is bolted solidly to the generator frame, while the rear end is permitted to move freely with temperature changes. The finned tubes are supported so as to eliminate vibration. The cooler tubes may be cleaned without losing gas from the generator housing by removing the nozzle and rear end water boxes, a flexible rubber diaphragm on the rear end between the generator frame and cooler serving to keep the gas in the generator. The gas coolers are installed so as to be readily accessible, and so as not to weaken the generator cylindrical shell.

The hydrogen-gas ventilating circuit is shown in figure 2. A propeller-type blower, consisting of a steel hub with aluminum blades, is mounted on each end of the rotor, and these circulate the hydrogen through the rotor and stator, where it picks up heat, and then through the finned-tube gas coolers, where the heat is transferred to the cooling water in the tubes. The cooling gas may complete 30 to 40 such circuits in a minute. The interchange of cooling gas between the two ends of the generator is very small, so that both coolers are required when the generator is running. Hydrogen-cooled generators are designed to carry at least 75 per cent rated load, with normal temperature rises, running air cooled.

Manholes in the end domes, and portlights on the side of the generator are provided so as to permit observation of the internal machine parts without disassembling the generator end domes.

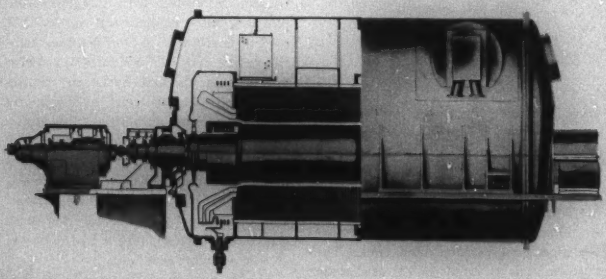

Figure 2. Longitudinal section view of a 53,000-kw hydrogen-cooled generator with direct-connected exciter

The generator tool-steel collector rings, spiral grooved to improve commutation, are located outside the generator bearings. The main and pilot exciters are driven at the same speed as the generator rotor, and have one or two bearings, depending on the size of the exciter. Two-bearing exciters are flexibly connected to the generator rotor. The special floating-type commutator on the exciter provides satisfactory operation at 3,600 rpm.

Description of Generator Shaft Gland Seals and Oil System

A hydrogen-cooled generator requires shaft gland seals on each end of the generator rotor to keep the hydrogen gas in and the air out of the generator housing. The shaft gland seal details are shown in figure 4. The special feature of the shaft gland seal is the sealing rings which are located in grooves in the seal member and are fitted close to the shaft and are free to move with the shaft radially, but are pinned so that they cannot rotate with it. These sealing rings reduce the flow of oil to a relatively small quantity, approximately one gallon per minute to each seal. Gland seal oil is supplied at approximately five pounds per square inch behind the sealing rings, and this oil flows out to the rotor shaft through radial holes in the sealing rings. The oil then flows both ways from the center of the sealing rings, part toward the air side of the seal and part toward the hydrogen side of the seal. As long as gland seal oil pressure is maintained, hydrogen gas will not escape along the shaft even if the gas pressure approaches that of the hydrogen gland seal oil pressure. The gland seal oil leaving both the air and hydrogen sides of the seals is collected and returned to the gland seal oil reservoir. A very small amount of gland seal oil is lost to the main bearing oil at the shaft gland seals.

The relation of the various elements which comprise the complete gland-seal-oil-supply system is shown diagrammatically in figure 5. The gland seal oil that is drained from the hydrogen side of the sealing rings flows by gravity to the defoaming tanks, where the foam is permitted to settle out, before the oil is returned to the gland-seal-oil reservoir. This defoaming tank also acts as a valve in case of an explosion in the generator as sufficient oil is provided in the tank, and the oil and gas passages are of such relative size, that it cannot be emptied in the 10 to 15 seconds in which the machine pressure might be above atmospheric pressure. This prevents driving hydrogen gas into the main and gland oil reservoirs under such conditions.

The gas pressure in the generator and

defoaming tanks is balanced by a column of oil in the loop seals located beyond the defoaming tanks.

The gland-seal-oil reservoir is integral with the main oil reservoir, but the oil interchange between these two tanks is very small. Sufficient oil from the main-bearings oil-return line is admitted to the gland-seal-oil reservoir by the float-controlled valve to make up that gland seal oil that is lost to the bearing system at the shaft gland seals.

It is necessary to remove the gas and moisture from the gland-seal-oil supply by a vacuum-treating process, otherwise the oil leaving the hydrogen side of the shaft gland seals would liberate gas and moisture in the generator housing and this would reduce the hydrogen purity. In the vacuum-treating unit the gland

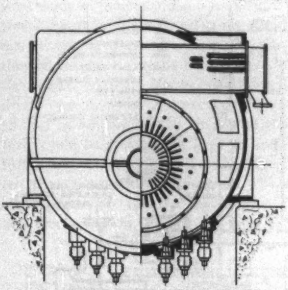

Figure 3. End section view of a 53,000-kw hydrogen-cooled generator showing the gas-cooler arrangement

seal oil is subjected to a vacuum of one inch mercury absolute or less. As the oil is sprayed into the vacuum, the water flashes into steam, and the entrained gas in the oil expands and bubbles out of the oil. The vacuum pump draws these gases out of the vacuum tank, discharging the gases out the vent to outside, and draining the water out of the separator tank just beyond the vacuum-pump exhaust. The vacuum-treating unit is so arranged that it may be segregated from the gland seal oil supply system for a limited time for inspection and maintenance without materially affecting the operation of the generator. Continued operation without the vacuum-treating unit would result in air being liberated into the generator housing and the addition of hydrogen would be required to maintain the hydrogen purity in the generator.

The shaft-gland-seal-oil supply is normally secured by an oil-turbine-driven oil pump, using high pressure oil from the impeller on the turbine shaft for driving power. If this pump should fail, a pressure-operated Mercoid switch operates to start an electric-driven seal oil pump. Also an emergency connection is provided between the main bearing supply system and the gland seal oil supply system, whereby a diaphragm-operated regulating valve operates to admit bearing oil pressure to the gland-seal-oil system in case the pressure drops to approximately three pounds per square inch. Shaft gland seal oil is thus guaranteed so long as the generator rotor is running. When using the main bearing oil for the shaft gland seals through the emergency connection, it is necessary to add hydrogen from time to time to maintain the hydrogen purity. The vacuum-treating unit should not be operated when the emergency seal supply system is used.

An important feature of the gland-seal-oil supply and main-bearing oil supply systems is the ventilating blowers which are direct connected to the gland-seal-oil supply pumps. These ventilating blowers create a vacuum of about two inches of water pressure in the gland-seal-oil and main oil reservoirs, in the main-bearing drains, and in the bearing pedestals. All of the bearing drain lines are designed so as to flow partially full of oil, leaving a ventilating passage. There is, therefore, a flow of ventilating air through the labyrinth oil sealing strips at the bearing pedestals, which air flows through the partially full oil drain lines to the main oil tank, thence to the gland-seal-oil reservoir, and through the ventilating blower to the vent to outside. Hydrogen accumulation in the pedestals and drain lines, and oil tanks, is thus eliminated.

Gas Control System for Hydrogen-Cooled Generator

The gas control system is shown schematically in figure 6. The principal functions of the gas control system are to provide means for maintaining the hydrogen in the generator within the proper purity, pressure, temperature, and moisture limits; and to provide means for filling and scavenging the generator housing with gas; and to warn the operator when operating conditions are not normal.

Figure 6 illustrates the gas control system during normal operating conditions. The hydrogen pressure in the generator housing is automatically maintained at approximately 5 to 10 inches of water pressure in order to prevent air leakage into the generator housing. A Mercoid pressure switch energizes the solenoid hydrogen inlet valve when the gas pressure drops to about 5 inches of water pressure. A diaphragm operated relief valve regulates the upper pressure

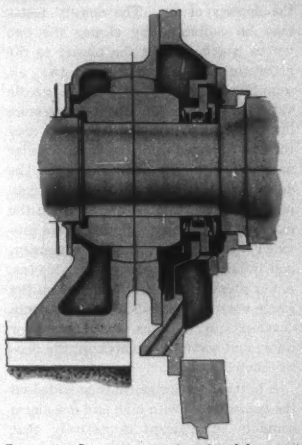

Figure 4. Section view of pedestal bearing and shaft gland seal for a hydrogen-cooled generator

limit by exhausting gas to atmosphere at approximately 20 inches of water pressure. A push button is located on the gauge board for manually operating the solenoid hydrogen inlet valve to increase the hydrogen purity, the excess pressure resulting from the hydrogen admission being released by the diaphragm-operated relief valve.

A machine gas pressure gauge, containing high and low alarm contacts, is located on the gauge board. Also another pressure gauge is located adjacent to the manual gas-supply bottles so that the operator can observe the machine gas pressure during the scavenging and filling operations. Both of these pressure gauges are of a special design capable of withstanding the explosion pressure, although the full-scale range is only 0 to 60 inches of water pressure.

The purity of the hydrogen gas in the generator housing is indicated on the gauge board by a "density meter" which gives a direct check on the hydrogen purity as the density of hydrogen is much less than the density of air. The density-meter blower runs at constant speed, being driven by a lightly loaded induction motor, and samples the machine gas continuously. The pressure developed

by this blower is directly proportional to the density of the gas, and this pressure is used to actuate the density meter on the gauge board which is merely a 0 to 20 inches of water differential pressure gauge. The density-meter dial is graduated 0 to 150 per cent density, 100 per cent density being arbitrarily taken as the density of air. The density meter may be calibrated by closing the two valves which connect the blower to the generator, and opening the two air sampling valves. The orifice needle valve which connects the two pressure lines leading to the density meter may then be adjusted until the density meter indicates 100 per cent density. The density meter blower can then be connected so as to sample and indicate the machine gas density. Contacts are provided for indicating high gas density, and failure of the density meter blower. A fan pressure gauge is provided on the gauge board which indicates the pressure developed by the fans on the generator rotor, and serves as a check on the density meter.

A bottle-pressure gauge is provided on the gauge board with high and low alarm contacts to indicate respectively that the gas reducing regulators at the automatic hydrogen supply bottles have failed or that the gas bottles are empty and require replacement. Also an indicating thermometer with a high alarm contact is provided on the gauge board to indicate the gas temperature in the generator housing.

Hydrogen-cooled generators require a small gas dryer which removes a small amount of moisture from the gas in the generator housing, and thus keeps the dew point of the cooling hydrogen below the temperature of the gas in the cooler tubes, and prevents condensation within the generator. Hydrogen is circulated through the reactivated alumina dryer by means of the generator fan pressure. At approximately weekly intervals, the dryer is disconnected from the generator and reactivated by heating the activated alumina and blowing room air through the dryer tank, these operations being readily performed by operating valves provided and starting the heater and air blower. The normally blue activated alumina crystals turn gray when full of water, as evidenced by the sight glass on the side of the dryer tank.

Water detector float switches are connected to the low points in the bottom of the generator frame, and these sound an alarm when full of water, indicating water is collecting in the generator.

When operating conditions are abnormal, an alarm is sounded at the gauge board and a signal light indicates the source of the alarm. The following alarms are normally provided on a hydrogen-cooled generator:

1. High gas density
2. Low gas density
3. High gas pressure
4. Low gas pressure
5. High bottle pressure
6. Low bottle pressure
7. High gas temperature
8. Water detector full
9. Gland low oil pressure
10. D-c power supply off
11. Vacuum oil treating unit

The gas supply bottles and operating valves are usually located conveniently under the generator. A manual supply of hydrogen and carbon dioxide is provided for filling and scavenging the generator housing with hydrogen. It is necessary to scavenge the oxygen from the generator housing with an inert gas, such as carbon dioxide (or nitrogen) before introducing the hydrogen into the generator housing to prevent mixing of air and hydrogen. Two volumes of inert gas will reduce the oxygen content to a safe figure for introducing hydrogen. Three and one-quarter volumes of hydrogen are then required to bring the hydrogen purity up to 95 per cent hydrogen. The density meter may be used to check the various gas purities.

During normal operation of a hydrogen-cooled generator the gland seal oil carries air in and hydrogen out of the generator. An air in-flow of one cubic foot requires the addition of 24 cubic feet to maintain the hydrogen purity at 95 per cent. When it is required to remove the hydrogen from the generator housing, approximately three volumes of inert scavenging gas are required to reduce the hydrogen purity to a safe figure for adding air.

Operating Experience

The first unit to be filled with hydrogen went into operation on May 5, 1938. Since that time, four other units have gone into operation with hydrogen cooling. Hydrogen gas used by these machines runs from 20 to 90 cubic feet per day when the generator is running and considerably less when the generator is shut down. Some gas is lost due to variations in machine gas temperature which causes fluctuations in gas pressure sufficient to operate the relief valve. Gas purity remains at well over 95 per cent without adding gas to improve the mixture showing that the infiltration of air with the gland seal oil is quite small.

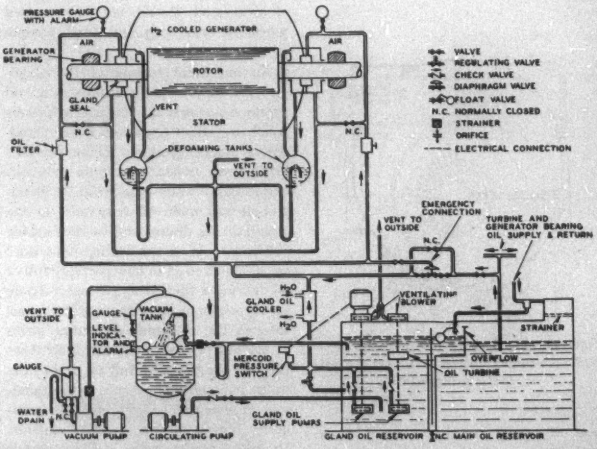

Figure 5. Schematic diagram of the shaft-gland-seal oil-supply system for a hydrogen-cooled generator

As in nearly every radically new design, some troubles were encountered at the outset. Shortly after the first unit started up with hydrogen, water was noticed in the water detectors connected to the bottom of the machine. While the quantity was not large, its presence was disturbing. After some investigation, it became apparent that the water

in the generator was coming from the gland seal oil. Small quantities of water in the gland seal oil were being evaporated at the shaft sealing glands on the hydrogen side and the water vapor eventually found its way into the generator by diffusion through the gas. When it entered the generator, the moisture content of the gas increased until the dew point reached the temperature of the tubes of the gas coolers. Water then condensed on the cooler tubes and ran down into the water detectors. As originally designed, the shaft sealing glands used oil from the lubricating system without special treatment other than running it through baffles in the gland seal tank to remove air bubbles. Any water that got into the lubricating system was, therefore, likely to be taken over into the generator. To overcome this situation, three changes were made in the machines. A vacuum-treating system was inserted in the gland seal oil system to remove the major portion of the water in the oil pumped to the shaft sealing glands. Additional drains were installed in the sealing glands so that oil coming off the air side of the seals could be caught and kept separate from the lubricating oil and drained back to the gland-seal-oil reservoir. This move practically isolated the gland seal and lubricating oil systems one from the other so that the vacuum-treating system was required to treat the same quantity of oil over and over again rather than to be treating a large amount of oil from the lubricating system.

Tests at the factory on a shaft sealing gland showed that even though the vacuum system reduced the water in the oil to less than 0.003 per cent, a certain portion of this small quantity of water would get into the generator and would in time raise the dew point to the saturation point corresponding to the cooler tube temperature. A small dryer of the activated-alumina type was, therefore, connected into the gas system so that a small portion of the hydrogen would be circulated continuously through the dryer to remove the last traces of moisture that might get into the generator.

These three changes have proved to be entirely satisfactory in keeping water out of the generator. The addition of the vacuum-treating system and the dryer have added very little to the work of the station operators and it should be noted that neither piece of equipment is vital to continuous operation and can be cut out of service at any time for several hours for inspection without affecting the operation of the generator.

One other major trouble encountered was the excessive vibration of the tubes of the gas coolers which resulted in wear of the fins on the tubes where they passed through the tube support plates. As pointed out in a companion paper, the two-pole generator stator is subject to double-frequency vibrations set up by the magnetic field. This vibration is always present in such machines but had not been recognized as important until these large-diameter two-pole machines were built. It was not recognized that a cooler construction suitable for mounting on the foundation of the unit would not be adequate when closely connected to the frame of the generator. As soon as the problem was realized, the solution of adding extra tube-support plates in the coolers to change their vibration periods became apparent. A number of other detail changes were also made and no further trouble from this source has developed.

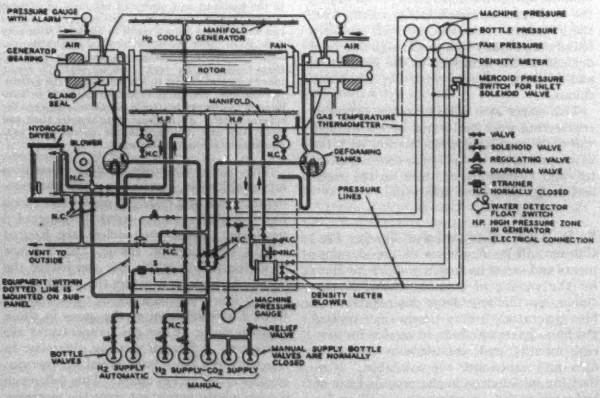

Figure 6. Schematic diagram of the gas control system for a hydrogen-cooled generator

Exciters

This paper would not be complete without some mention of direct-connected exciters for the large 3,600-rpm units. While some doubts were expressed by the purchasers at the time of buying these large units, concerning the possibilities of trouble with exciters up to 165 kw rating at 3,600 rpm, their operation to date has been entirely successful. A 65,000-kw unit is now on order for which a direct-connected 260-kw exciter will be provided. All the large units have been provided with pilot exciters with armatures overhung on the end of the main exciter shafts.

Conclusion

With operating experience on a number of units and over a considerable period of time at hand, the initial stage of development of hydrogen-cooled generators is passed. There will no doubt be minor difficulties to correct as time goes on, but these will be of no more serious nature than are to be found in air-cooled generators. It will also be possible to simplify considerably the generator and its attendant parts in future machines as greater experience is gained with this type of machine. Cost of supplying hydrogen gas is very low, and it has been the experience in most stations that the additional attention on the part of the operators as compared to that for an air-cooled machine is very small. Hydrogen cooling will probably be adopted more and more for units of 30,000 kw and above where the additional cost of the gas-tight housing and gas control can be justified economically.

The adoption of hydrogen cooling for large machines has enabled the size of 3,600-rpm machines to be pushed up to 81,250 kva at 80 per cent power factor. With further experience, it will no doubt soon be possible to build 100,000 kva, 80 per cent power factor at 3,600 rpm with this method of cooling.

References

1. Fundamentals of Heating Calculations of Electric Machines, R. Pohl. *Archiv für Elektrotechnik*, volume 12, 1923, page 301.

2. Hydrogen as a Cooling Medium for Electrical Machines, Edgar Knowlton, Chester W.

Rice, and E. H. Freiburghouse. AIEE Transactions, volume 44, 1925, pages 922–34.

3. Liquid Film Seal for Hydrogen Cooled Machines. Chester W. Rice. *General Electric Review*, November 1927, page 516.

4. Hydrogen Cooling of Large Electrical Machines, C. J. Fechheimer. *Electric Journal*, March 1929, page 127.

5. Outdoor Hydrogen-Ventilated Synchronous Condensers, Robert W. Wieseman. AIEE Transactions, volume 48, 1929, pages 1221–6.

6. The Application of Hydrogen Cooling to Turbine Generators, M. D. Ross. AIEE Transactions, volume 50, 1931, pages 381–6.

7. Hydrogen Cooling of Rotating Machines, C. M. Laffoon. AIEE Transactions, volume 55, 1936, pages 703–09.

8. Hydrogen-Cooled Generators, E. H. Freiburghouse and D. S. Snell. *Power*, August 1938, page 40.

Discussion

Sterling Beckwith: See discussion, page 38.

S. H. Mortensen: See discussion, page 48.

C. F. Hill and L. J. Berberich: See discussion, page 48.

D. S. Snell (General Electric Company, Schenectady, N. Y.): I wish to compliment Messrs. Ross and Sterrett on the stator-frame construction developed for their hydrogen-cooled generators, which allows the use of somewhat larger and more accessible coolers for given shipping dimensions than practicable with the conventional round frame construction. In our designs, we have preferred the use of four coolers placed lengthwise of the casing, in place of the two-cooler-crosswise arrangement, to permit removal of any one cooler from service without shutting down the machine, and at the same time maintaining uniform temperature distribution in the cooling medium.

The type of shaft sealing gland described in this paper has the advantage over the solid-ring type of seal, constructed integral with the bearings, of requiring a considerably lower oil flow, and thereby reducing the size of the oil-treating equipment. However, it has the disadvantage of having loose parts which may under certain circumstances seize the shaft and be destroyed, and also introduces the possibility of misalignment with the shaft, which is not present with the solid-ring type of seal. While we are using a shaft seal of the floating-ring type with some of our 1,800-rpm hydrogen-cooled generators, we consider the solid-ring type of seal to be preferable with generators of the 3,600-rpm class, since machines of the latter class are more susceptible to vibration difficulties.

In connection with the seal oil supply system described in this paper I would suggest that a slight improvement in the degree of vacuum treatment of the gland sealing oil would result in obtaining an appreciable increase in the percentage hydrogen purity held in the generator casing and would also decrease the amount of moisture entering the casing through the gland seals. I would ask the authors if they do not consider the effectiveness of their vacuum-treating system to be somewhat reduced by the reabsorption of air by the oil in the gland oil reservoir. Tests by F. M. Clark, reported in the *Journal* of the Franklin Institute, volume 215, 1933, page 39, showed that vacuum-treated oil exposed to air in an open vessel absorbs air rapidly, and I should think that the extensive oil surface exposed to air in the gland oil reservoir would permit a considerable absorption of air by the oil. Much of this reabsorption of air could be prevented by simply floating a board on the oil surface.

I note that no provision is made for automatically interrupting the vacuum in the event of failure of the circulating pump, to prevent flooding the vacuum pump with oil foam, and presume this is done manually. With the system described in my own paper an automatic interrupting device is used, due to the relatively high vacuum maintained in the vacuum tank, which would cause the tank to fill quickly with oil foam following a shutdown of the circulating pump if the vacuum were not interrupted.

The use of a dryer for the hydrogen within the generator casing such as is described in this paper, has not been found necessary with our own hydrogen-cooled generators. This may be partly due to the relatively high degree of vacuum treatment of the shaft sealing oil which is obtained, and also to the fact that a small dryer is provided in connection with the hydrogen-purity indicator. During the first few weeks of operation, however, considerable moisture is present in the casing as a result of the casing having been open to atmosphere, which requires rather frequent renewal of the dryer of the purity indicator. We have provided, with our earlier machines, a dryer for drying the hydrogen admitted to the casing from the hydrogen containers, but this has been found unnecessary due to the high degree of dryness of the hydrogen in the containers, and is being omitted with our later machines.

This paper is a tribute to the extensive engineering work performed by the authors and their associates in connection with the development of the hydrogen-cooled generator, and I congratulate them on the excellent design they have achieved.

F. D. Troxel (Sargent and Lundy, Inc., Chicago, Ill.): A review of the developments and use of hydrogen gas as a medium for the cooling of rotating electrical machines, particularly large high-speed turbine generators, is very timely since several machines have now been in service for several months and considerable operating data and experience are available. Now that the initial steps in the practical use of hydrogen-cooled generators are well under way, there are several facts which are quite evident:

1. That larger and more efficient hydrogen-cooled generators can be successfully built into a given space than air-cooled machines.

2. That the shaft seals which were long the subject of much discussion and many costly experiments, are operating without any serious trouble and with a small amount of gas leakage.

3. That the fear of disastrous explosions is rapidly disappearing.

The authors have prepared an excellent paper and have discussed the design and operating experience of hydrogen-cooled generators, particularly from the viewpoint of the manufacturer. While the operation of hydrogen-cooled generators, has, in general, been considered satisfactory, from the operating company's viewpoint there are certain improvements and developments which should be made in connection with future machines, namely:

A. The hydrogen auxiliaries should be simplified and reduced in number.

B. Means should be developed for taking the hydrogen out of the generator and for refilling in a much shorter time.

C. Standardization of the explosion strength requirements of the shell should be adopted to cover both distortion and failure, and standardization of factory tests to prove the design. Before adopting any standards relative to shell strengths, the question of the real necessity of explosion-proof shells, and their economic justification should be carefully considered.

In connection with the planning and installation of hydrogen-cooled generators, there are certain precautions which should be kept in mind, as follows:

A. All oil tanks and connecting pipes should be carefully vented and grounded. Several small explosions have resulted from lack of attention to these details.

B. There should be no pockets under the generator and around the generator foundation in which gas can collect. If such pockets are unavoidable, some type of ventilating system is required to keep the air slowly moving through these areas.

C. It is desirable for safety reasons to store the hydrogen-supply bottles outside of the building. By locating the hydrogen-supply bottles outside of the building and there connecting them to a header piping system which pipes the gas into the generator, the amount of hydrogen in the building is reduced by about one-half, assuming a normal supply approximately equal to that in the machine. This is desirable from safety and insurance consideration. If the bottles are stored and racked outside of the building on a sheltered platform of suitable height located alongside a driveway, the bottles can be unloaded from a truck or reloaded with very little labor. On the other hand, if the bottles are located under the machine, it is necessary to unload them from a truck, pick them up with the crane, move and lower them to a position near the generator, and then roll them into their rack. The handling of the empty bottles is, of course, similar in the reverse order. All of these steps require time and labor, the cost of which in the course of a year amounts to a considerable sum.

The use of hydrogen cooling introduces one problem in connection with the temperature rise and rating of generators which has not been encountered in air-cooled machines. Since the coolers are located within the machine casing, the distance from the points where the gas leaves the coolers and where it enters the laminations, is very short, and as a result, there appears to be a stratification of the gases in those areas in so far as the gas temperatures are concerned. Several degrees difference in temperatures have been noted on thermocouples a few inches apart. This difference is particularly important since the temperature-detector elements upon which the temperature rise of the generator is determined are located in these areas. This condition does not exist in the air-cooled machines, since the coolers are generally located some distance from the generator, and the cooling medium is thoroughly mixed and has reached a uniform temperature when it enters the generator.

As a result of this condition, it has been suggested that for hydrogen-cooled machines the temperature of the cooling water in going to the air cooler be used as a base, that

the temperature rise be determined from this base, and the rise so determined be used in the guarantees and in the determination of hydrogen-cooled generator ratings in a manner similar to that which has been used for many years in connection with water-cooled transformers. We feel that this suggestion has considerable merit.

C. C. Sterrett: We wish to thank the following gentlemen for their discussions of our paper: S. H. Mortensen, Sterling Beckwith, F. D. Troxel, D. S. Snell, C. F. Hill, and L. J. Berberich.

Mr. Mortensen's comments relative to removing air or gas from the generator housing by evacuation are interesting. We have preferred to use the inert-gas method of removing air or gas from the generator housing because we believe this is simpler and has considerable advantages not provided by the evacuation method.

In hydrogen-cooled turbine generators of our design, three-fourths load may be carried, air or CO_2 cooled. We are, therefore, able to change the gas in the generator housing with three-fourths load, whereas if the evacuation method were used, the generator load would have to be reduced to zero while the generator housing was evacuated.

The possibility of a fire in a hydrogen-cooled machine, or of a failure of the gas control or oil system is rather remote, but if this should occur, it would be desirable to have a positive means of scavenging the generator housing readily. This may be done with a CO_2 scavenging system, whereas the evacuation method would require a vacuum pump or ejector, and it might be that the power for operating this equipment would not be available when required.

We are able to scavenge air or hydrogen from our generator housing with CO_2 in less than 45 minutes, and we doubt that the evacuation method would reduce this time unless a very large vacuum pump or ejector were used.

The only advantage of the evacuation method is that it require slightly less hydrogen for the filling operation. In our gas system, two volumes of hydrogen are required to fill the generator at standstill, whereas with the evacuation method, Mr. Mortensen points out only $1^1/_2$ volumes of hydrogen are required. Since the additional hydrogen required by our method would cost about $15 a filling, we cannot justify the evacuation method. We are able to add the necessary hydrogen to our generators when running (four volumes) in an hour or less and this time is reduced in half when the generator is at standstill.

Mr. Mortensen informs us that he has found seal oil treatment unnecessary in his design. Our experience does not bear this out. Turbine oils, and especially those used in "topping units," contain traces of water. This water will be liberated into the generator housing at the shaft seals and will eventually build up the dew point in the generator. We would suggest Mr. Mortensen measure the dew point of the gas in their hydrogen-cooled machines. We believe he will find a high moisture content in the gas in the generator housing. As pointed out in Messrs. Berberich and Hill's discussion of our paper, low moisture content in the generator housing is very desirable.

Sterling Beckwith's suggestion to simplify the gas and oil systems of hydrogen-cooled machines is timely. In our paper, the statement is made that we have passed through the development era of hydrogen-cooled turbine generators, and we are now turning our attention to simplification of the auxiliary equipment. Hydrogen-cooled turbine generators which are now in operation require no more attention than a corresponding air-cooled machine. We have probably been too conservative in the design of our auxiliary equipment, and are now simplifying our equipment so that it will require much less attention. The operating companies have accepted hydrogen cooling very favorably and have offered many valuable suggestions which will aid in simplification of our auxiliary equipment.

We do not expect to eliminate the relief valve as suggested by Mr. Beckwith. Our later machines are equipped with a very simple relief valve, and we set it to release gas at a pressure above the normal operating pressure range. The relief valve acts to limit the pressure; however, excess pressure resulting from failure of the inlet system would do no harm. We believe it is desirable to keep the gas pressure under control automatically. As pointed out by Mr. Beckwith, the relief valve does not aid in reducing the explosion pressure by releasing gas, since the explosion pressure only lasts a few seconds.

Mr. Beckwith suggests that operation of hydrogen-cooled generators at higher pressures might not be justified due to increased hydrogen consumption. We expect to be able to build gas-tight housings for turbine generators which will not require more than 100 cubic feet of hydrogen per day to maintain 15 pounds in the generator. The cost of this gas will be insignificant with respect to the value of the additional load available at the higher operating pressures.

We enjoyed reading F. D. Troxel's discussion because it represents the operating companies' viewpoint. Mr. Troxel suggests it would be desirable for safety and operating reasons to store the hydrogen bottles outside the building. We do not believe this is necessary from a safety standpoint, but we agree that it might simplify the handling of the hydrogen bottles. So far as we are concerned, the hydrogen and CO_2 supply may be located wherever the customer desires, but we have left this location up to the customer.

Mr. Troxel further suggests that the temperature of the cooling water going to the gas coolers should be used as a base instead of the gas temperature leaving the coolers, for determining the temperature rise used in guarantees. We are in full agreement with Mr. Troxel on this point and we favor a standardization program on this basis.

Relative to Mr. Snell's discussion, we have the following comments. In our earlier generators we provided two gas coolers placed crosswise in the generator housings. Each cooler had a single section and it was necessary to shut down the generator for servicing either or both gas coolers. Operation with these machines has been very satisfactory. However, in our later design we have installed two and three sections in each of the two coolers and a section may be cleaned at a time without reducing the load on the generator. Mr. Snell has suggested that the type of shaft seal used in our design has the disadvantage of having loose parts which may fail, or not be aligned with the shaft. We disagree with Mr. Snell and point out that the floating-ring type seal which we are now using has operated satisfactorily in seven machines for a considerable time on both 1,800- and 3,600-rpm machines. The floating-ring type seal we use is similar to the seals which have been used with success on turbine shafts for a number of years.

Relative to Mr. Snell's comments on the effectiveness of our vacuum-treating unit, we refer to our paper under "Operating Experience." We stated there that our machines were using 20 to 90 cubic feet of hydrogen per day and maintaining hydrogen purity well above 95 per cent. We believe this indicates satisfactory performance of our seal oil system. Mr. Snell has questioned as to how we control excess foaming in the vacuum oil tank. We do this with a "vacuum breaker," which admits a small amount of air and breaks the foam. The vacuum breaker is operated by a float which rides the foam in the vacuum tank. It is our experience that an excess amount of water will overload the vacuum tank and cause foaming. In our design this operating condition is taken care of almost instantly by the vacuum breaker.

We wish to take this opportunity to compliment Mr. Snell on the splendid paper he has presented on hydrogen cooling. He has covered the subject of hydrogen cooling thoroughly, and in our opinion left very little open for discussion.

Electrical Equipment on Machine Tools

B. P. GRAVES
NONMEMBER AIEE

THIS is an interesting opportunity to speak to electrical engineers, to praise them for the excellent motors and controls which have helped us to improve the performances of machine tools, and yet to prod them a bit about a few features of their designs which are obstacles to a greater use of electrical equipment. This paper is thus a partial report to electrical designers describing some of the recent applications of electrical equipment to machine tools and outlining a few of the problems which have been encountered.

Machine tools are rapidly becoming motor-drive machines. Ten years ago we would estimate that about 40 per cent of the machines made by Brown and Sharpe were motor driven. Today over 90 per cent are equipped with motors and many new machines are being designed solely for individual motor drive with no provision for overhead group drive. Not only has there been a shift from group to motor drive, but there has been an increase in the number of motors used on machines. Today milling machines commonly employ three individual motors while grinding machines require from five to seven separate motors.

Now if individual motors are to be used to drive various units of a machine, it is a logical step in design to use more fully the abilities of these motors, to interconnect their controls, and to co-ordinate their functions. Thus instead of engaging and disengaging a clutch to start and stop a mechanism, the driving motor may be started and stopped. Instead of applying a mechanical brake, a motor may be plugged to rest, and in place of a reversing clutch, the motor may be reversed.

Electrically Controlled Milling Machine

The milling machine shown in figures 1 and 2 successfully uses these natural functions of its motors. This is a plain milling machine in which separate shell-type motors drive the spindle and table. The table starts, stops, and reverses with its motor. In stopping the motor is plugged to rest or to the point where it actually makes a few revolutions in the opposite direction. The coast of a few turns in the opposite direction withdraws the work a few thousandths from the cutter, but has no influence on the point of farthest table advance or the point of reversal. By reversing and plugging the motor, it is possible to maintain with great accuracy, the point at which it is desired to stop a cut or to reverse in the cut when cutting to a shoulder. A small motor can stop in less than two revolutions when plugged. With an 1,800-rpm motor, producing a two-inch feed rate, two revolutions represent about 0.002 inch of table movement. Variations in stopping movement due to changes in line voltage might be as much as one-half motor turn which would mean 0.0005 inch at the table. Now of course variations in the operating time of control devices will have an influence on the reversal position yet even with these, the point of table reversal is maintained with surprising accuracy. For example, it is possible to take a very deep heavy cut in which the table is reversed by a table dog while in the cut. The curved surface left by the cutter on the work may be coated with Prussian blue and the table cycle repeated. The cutter will just kiss the blued surface, but will not completely scrape the color from the surface. The cycle may be repeated many times with the cutter always touching the blued surface yet never completely removing the original surface. For such accuracy of reversal, credit is given to the motor and controls for in mechanical designs, we have not obtained this degree of accuracy.

Figure 1. Electrically controlled plain milling machine

Figure 2. Control compartments on milling machine

A clutch shifted by a solenoid gives feed and fast travel rates of table movement. Using a solenoid to shift the clutch, it becomes comparatively easy to tie in the spindle rotation with the movement of the table. In a normal cycle the cutter spindle will rotate only when the table is moving at a feed rate. A selector switch provides other possibilities where the spindle rotates continuously or rotates only when the table is in motion. This interrelation of spindle and table movements is a feature obtained quite readily in an electrically controlled machine. This same feature is not available in mechanical designs.

When cutting to a shoulder, the table feed is usually stopped by a shift from feed forward to fast travel in reverse. In this move, it is essential that the shift to fast travel be delayed until the motor has been reversed or has at least reached zero speed in its reversal. If quick traverse is engaged before this, the table will jump ahead, jamming the work into the cutter. To obtain the desired sequence of action, a viscosity switch is employed. This is a switch which is controlled by

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the direction of motor rotation. Typical switches are shown in figures 3 and 4. The inner drum is mounted directly on the motor shaft and the outer cylinder is rotated a few degrees by the viscous drag of a 0.002-inch film of oil. The circuit of the clutch solenoid is held open by the viscosity switch and is closed only when the motor has completed its deceleration and is moving in the reverse direction.

Since the viscosity of an oil changes rapidly with temperature, a viscosity switch cannot be expected to act at exactly the same point each time the motor is stopped by plugging. A switch may be expected to open somewhere between a speed of 500 rpm and zero or if a very light restoring spring is used between zero and −500 rpm. Since a few thousandths table drift away from the cutter is not only acceptable, but desirable, the zero to −500 rpm zone has been adopted for the table motor. In stopping, the motor always passes through zero speed and makes a few revolutions in the opposite direction. A solenoid-operated detent prevents the switch drum from being carried through neutral to make contacts on the opposite side as would be done in a complete reversal.

The cutter spindle motor is plugged to rest. Here the switch springs are selected to overcome the viscosity drag when the motor reaches the 500-rpm-to-zero speed range. The plugging is stopped before the motor reaches zero speed, but in plugging, a 3,600-rpm motor to 500 rpm or less 98 per cent of the kinetic energy has been absorbed and a light-duty brake can be used to bring the motor to a complete stop and hold it there. A solenoid releases a spring which applies the mechanical brake as soon as the viscosity switch opens the control circuits.

Making more complete use of electrical equipment, it is possible to adopt a two-speed feed motor. A mercury switch tipped by table dogs selects the high or low table feed. With the possibility of halving feed rates at desired points in the cut changes in depth or width of cut can be more readily handled. Change of feed during a cut is a feature made possible by the use of electric controls. It is a feature which has not been offered in mechanical designs.

One other interesting advantage of an electrically-controlled machine is that the machine can be made inoperative as soon as any door or cover is opened. The doors of the spindle and table gear cases of this milling machine both open motor control circuits and make it impossible to start the machine accidentally while gears are being changed.

Electrically Controlled Grinding Machine

The electrically driven and controlled plain grinding machine shown in figures 5, 6, and 7 is probably the most completely electrified of any standard machine tool now made. It employs seven motors and two d-c generators; the direct current being used for variable-speed drives.

Briefly described, the machine has five constant-speed motors which are connected to the line and may be alternating current or direct current depending on the power supply. These constant speed motors are:

1. *Spindle Motor.* This is the main motor which is mounted on the wheelslide and drives the wheel spindle through a short V-belt drive. The motor runs all the time the machine is in operation.

2. *Coolant-Pump Motor.* This motor is started and stopped to start and stop the flow of coolant.

3. *Lubricating-Pump Motor.* Starting and stopping with the wheelslide motor, this motor-driven pump supplies lubricating oil to the entire machine.

4. *Wheelslide Quick-Return Motor.* (Figure 8) This motor with its solenoid-controlled brake, starts and stops each time the wheelslide is withdrawn from or advanced to the working position.

Figure 3. Spindle-motor viscosity switch

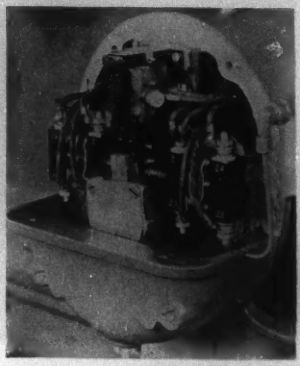

Figure 4. Table-motor viscosity switch

5. *Generator Motor.* (Figure 9) Running whenever the machine is in operation, this motor drives the two d-c generators.

Of the two generators, one is a constant-potential machine, and the other, a variable-voltage generator which is used in a Ward-Leonard table drive. The constant-voltage generator supplies power for relays and contactors, and for the fields of the variable-voltage generator and motor. In addition, it feeds the adjustable-speed motor used to drive the headstock.

The speed of this totally enclosed headstock motor may be varied through a four-to-one range by a rheostat connected in the field circuit. When the motor circuit is opened, a resistance is placed across the armature and rapidly brakes the headstock to rest.

The table motor is controlled by a rheostat in the field of the variable-voltage generator. Reversal of the generator field reverses the table motor. This Ward-Leonard drive was chosen because table loads were essentially constant-torque loads and because a low-speed motor having a small kinetic energy could be readily reversed. Since reversing contactors handle only the small generator field currents, light control units can be used. Speed changes of four to one (900 to 225 rpm) are obtained in the high-gear drive and eight to one (900 to 115 rpm) in the low-gear drive. To obtain an accurate reversal in the high-gear series the motor is slowed down to a low speed just before the reverse contact is tripped.

The outstanding advantage of a completely electric machine is the opportunity given to interconnect the controls of its various units. Controls can be simplified

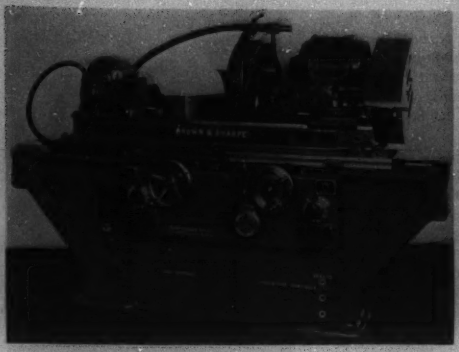

Figure 5. Electrically controlled plain grinding machine

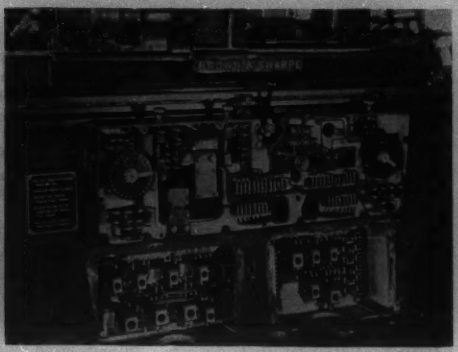

Figure 6. Machine of figure 5 with front plates removed

and co-ordinated, safety features can be easily incorporated, automatic control becomes possible, and in general the machine becomes more responsive to the operator. No other method of control can so easily tie together the various elements of a machine. This is the function of electric control which should receive greater emphasis and it is here that the electrical engineers can do some helpful work in the machine-tool industry. Machine tools are now using a large number of electric motors but the possibilities in controls are still to be developed.

Now taking the basic driving elements of the grinding machine just described, let me discuss a few of the possibilities in control. The piece to be ground having been placed in position, the operator must start the headstock, must turn on the flow of coolant, must start the table, and must bring in the cross slide to the grinding position. Four separate units must be controlled. If all of these are electrically powered as in the machine described, they can be simultaneously started by the rotation of the cross-slide handwheel. Four operations are thus easily replaced by one. When the piece is ground to size there are five steps to be taken: the wheelslide must be withdrawn, the table must be stopped, coolant must be shut off, power to the headstock must be disconnected, and a brake applied to quickly stop the work. By interconnecting controls all of these functions can be executed by a partial turn of the cross-slide handwheel.

An operator is traverse grinding with a table dwell at each end of the table travel and has controls centered in the handwheel. The grinding wheel must be trued. To do this the following moves must be made.

(*a*). Table dwell should be eliminated.

(*b*). A slow rate of table movement must be selected.

(*c*). As a safety measure the wheelslide quick return should be made inoperative.

(*d*). Normally the coolant pump and headstock start together. Here it is desired to start the flow of coolant, but to keep the headstock at rest.

(*e*). The controls centered in the handwheel should be separated so that the table and coolant flow can be started together by a control knob.

All these operations can, in an electric machine, be made simply by turning a selector switch or by changing the position of a knob from "grind" to "true." Having dressed the wheel, all original settings can be restored by turning the switch back to the "grind" position. No time is lost in resetting speeds and feeds, and there is no uncertainty on whether or not all the necessary moves have been made.

With electric control for all units of a machine, it is comparatively easy to break into the control circuits for the purpose of tying in special attachments or devices which are to take part in the operation of the machine. For some production jobs, automatic sizing or gauging devices are placed on the work. Such gauges can be wired to make or break a control circuit and thus to withdraw the wheelslide and stop the table, headstock, and coolant pump, leaving the machine ready for removal of the work.

In much the same way, an oil-operated piston can be placed in the lubricating system and can be wired to stop the entire machine whenever oil pressure becomes abnormally high or low.

The two machines described suggest some of the possibilities in machine-tool design which are offered by electric motors and controls. Through the wise use of electrical equipment machines can be given new abilities or features and can be made to perform standard functions with greater ease and increased accuracy. Of special importance are the gains which can be made through the use of electric controls. Most new machines will be motor driven and it is thus suggested that design development be focused on using to the fullest extent, the abilities of motors and on co-ordinating and simplifying their controls.

Controls

In starting out on the design of electrically controlled machine tools we realized that there were several characteristics of machine-tool service which were different from the service for which many control units had been designed. Life tests were thus made on a number of different makes and types of relays and contactors, to determine those which were best suited for our requirements. In these long tests, it was found that many standard relays and contactors performed poorly or failed completely in machine-tool service. Since electrical engineers are considering altering their designs to meet some of these new service conditions, it may be helpful to discuss these in detail.

Frequency of Operation

Electrical control equipment for machine tools should be designed to have a life of at least 10,000,000 cycles or operations. In the machine-tool industry, it is expected that machines will serve reliably for many years and any machine which requires frequent replacement of

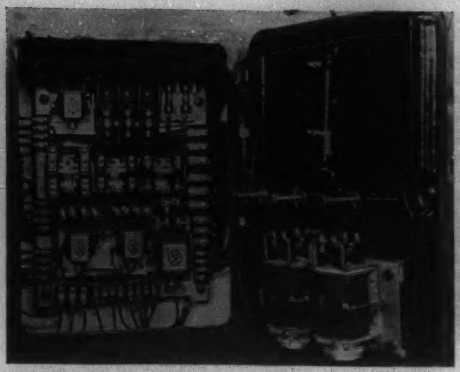

Figure 7. Side compartment for wheelslide controls

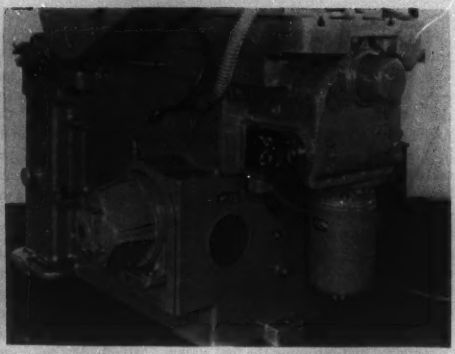

Figure 8. Wheelslide quick-return motor and cam control

parts is handicapped in its appeal to the trade. On production or manufacturing machines, control devices are operated almost continuously. Ten-second work cycles are common and in a complete cycle relays and contactors may be operated two or more times. With controls being energized every five seconds, it does not take many months to get into the million zone of operations. This is a far different service from that where controls are mounted on the walls of a room and operated a few times a day.

From the life tests we have conducted, it has been found that many standard controls have operating lives far under the 10,000,000 standard which we have tentatively adopted. With this number of operations, fatigue and wear failures were common. Pins and washers wore out, screws became loosened and springs, guides, and contact arms broke. Especially common were the failures of shading coils which wore or broke and caused noisy operation. In several cases these coils had failed in a few hundred thousand operations. Life tests frequently ended with the failure of the relay coils. The small wires with which the coils are wound, broke off at or just before the points at which they were joined to the coil terminals. The terminals were not well supported or anchored in the coil jacket or tape covering and the small movements and vibrations of the terminals caused a fatigue failure of the leads. It would appear that greater attention to the mechanical design of controls would improve their useful lives and would better qualify them for use in machine tools.

Certainty of Operation

Most machine tools of the manufacturing type have a fast travel movement which brings the work into cutting position. The point at which the shift from the fast travel to the feed rate occurs must be consistent, for operators set dogs for the shortest possible feed movement and variations in shifting position may cause the work to hit the cutter while still moving at the fast travel rate. As an example, the table of a machine moving at 300 inches per minutes is allowed a variation in shifting position of 1/16 inch due to variations in time of operation of electrical devices. This 1/16-inch represents but 1/80th of a second. If electrical equipment does not operate consistently within this variation limit, there will be occasional crack-ups in which cutters are injured or the work destroyed.

From life tests, it has been found that very few devices will consistently operate within the 1/80-second limit suggested. Designs which have several rubbing surfaces seem to be the least qualified to function with accuracy. Pin friction and losses in links and arms are variable and changes in friction conditions easily cause delays in operation, especially in the time of dropping out after being de-energized. Direct-acting units with simple movements have in our tests had the greatest consistency of operation.

After repeated operations, we were surprised to observe that relays and contactors would occasionally stick and fail to drop out or would be very sluggish in their dropping out. Examination revealed that the surfaces where the armature pressed against the pole faces were sticky. It was at first assumed that the black gummy coating was caused by dirt which had entered the control compartments. To check this, devices were operated in a sealed box. The same coating still appeared to cause sticking. Next, it was assumed that the varnished coils were contributing the gum and so unvarnished coils were tried with no success. It became apparent then that the laminated steel members of units were themselves contributing the gum. The varnish or resinous coating used as an insulating material on the iron sheets was very slowly working itself on to the seating surfaces. Baking the sheets had not prevented the coating from being hammered into a plastic gum.

On checking with other manufacturers, we learned that this trouble with sticking relays and contactors is common. Since the experience of having a relay stick is to a machine operator much the same as

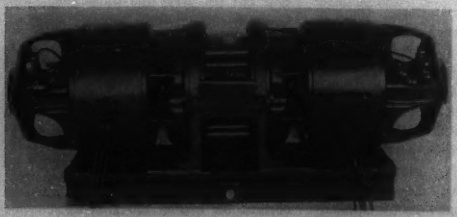

Figure 9. Motor generator set

that of a driver who steps on a brake to find it useless, it is suggested that electrical designers study the problem in their new designs.

By using intermittent-rated coils where the application permits it, it is possible to get greater pulls and thus use greater opening-spring pressures. These will make sticking failures less common, but the move is only a partial solution to the problem. Another partial solution is the use of two units in series. The probability of both devices sticking at the same time is of course far less than that of a single unit sticking. The best solution we have found is the use of opposed relays. As one is de-energized, the other is energized and assuming the first sticks, the second after moving one-fourth inch, gives the first a blow which is vigorous enough to separate sticking surfaces. Should the second coil fail, the first acts just as it would if the second were eliminated. The unit just described has the greatest certainty of operation of any device tested, thus far. The primary objection to this design is its cost.

Ease of Change for 50–60 Cycle

When machines are manufactured in lots of 25 to 100, it is necessary to insert motors and controls in order to run off and inspect machines before going into stock. Since many machine tools go abroad, it is frequently necessary to change these stock machines from 60 to 50 cycle. Motors are made for both 50/60-cycle service but controls are not so rated and must be changed over. It would be a great help to machine-tool builders if relays and contactors could be made for 50/60-cycle service. From tests we have made, it appears that present 60-cycle coils are fully qualified for 50-cycle service and it is difficult to see why manufacturers are so reluctant to give their coils a 50/60-cycle rating. If coils cannot be made 50/60 cycle then designers must simplify their devices so that one coil can be substituted for another in a few simple steps. We have had cases where it has been necessary to eliminate some makes of controls just because the devices had to be practically disassembled to substitute a 50-cycle coil for 60 cycle. In the same way inaccessible over-load heaters make change-overs costly.

Space Requirements

When a control unit is mounted on the wall of a room, a few extra inches in its space requirements are unimportant; however, when the same unit must be mounted in a machine casting, these marginal inches are of critical importance. They may limit the possible power movements of, or may upset the proportions of the machine. In general, the mechanisms in machine tools have been laid out with economy of space as a controlling factor in design. Gears, shafts, clutches, and cams, are assembled in compact units, for steam-shovel proportions cannot be accepted in a sensitive tool-room machine. On such a machine it is a difficult problem to mount electrical equipment and more compact units would greatly aid machine designers. At present, we use few limit switches and push-button stations in their original casings or housings, for these require too much space and have an awkward appearance when attached to the outer walls of a machine. Greater compactness and more economy in use of space would make electrical devices more readily adaptable for machine-tool applications.

Machine Wiring

In wiring a machine tool, it is well to assume that sooner or later, wires will be exposed to oil even though detail design steps have been made to keep them apart. In assembly or repair work, oil is often unintentionally admitted to wire ducts or terminal boxes, and when admitted, it is not likely to be removed. We have thus found it an economical practice to use the high-quality wires insulated with synthetic compounds which make them oil resistant. Wherever possible, ducts of ample size are cast in the machine bed so that wires may be well protected from physical contact with moving parts. It is also very helpful to use prepared harnesses in wiring, for, with wires cut to length, equipped with identifying tags and terminals, and bound together, individual wires do not have to be drawn through the machine and wiring becomes an easier job.

Although oil-resistant wire is available there is no oil-resisting tape to be used on these wires. Taped joints are equally as important as circuit wires and defense against oil will only be half complete until an oilproof tape is developed.

The problem presented by taped joints is aggravated by the terminal boxes on fractional-horsepower motors. Imagine totally enclosed motors being made with terminal boxes which resemble strawberry boxes with their open seams and corners. The fact that an enclosed motor, is specified, indicates that surrounding conditions will not be favorable and it is inconsistent to furnish a partially open terminal box on such a motor. A terminal box full of pasty rubber and slimy tape is a hazard in any motor application. Fortunately integral-horsepower motors have well-designed terminal boxes. It would be helpful to bring those on fractional-horsepower motors up to the same standard.

Conclusions

Two conclusions are suggested by this paper. First: that through the use of motor drives and electric controls, machine tools can be improved in performance and can be made simpler and easier to operate. Second: that many standard control devices are poorly qualified for machine-tool service and should be redesigned for this more frequent and exacting duty.

Discussion

P. H. Wilmarth (nonmember; The Blanchard Machine Company, Cambridge Mass.): Your paper on "Electrical Equipment on Machine Tools" was studied by several of my associates and we all have agreed that the build-up for your final conclusions carry many excellent statements of "constructive inference."

Your illustrations show the last word in good practice in applying both motors and control. The "Frequency" and "Certainty" sections are the meat of the whole situation because the final decision as to whether or not a mechanism should be used in preference to an electrical unit is finally rooted in the fact that ruggedness comes before low cost.

We have recently adopted a design to overcome the 50/60-cycle difficulties you mentioned. This merely consists of a 0.25-kva transformer with a dual-voltage primary (220/440) connected to one phase of the line and a dual-voltage secondary (110/95) for the entire control circuit so that the identical holding coils may be used on either frequency. Further merit comes from the safety feature of the low-voltage control circuit plus a flexibility of application on line voltages which will allow this one panel to be used on about 85 per cent of the machines for which it is designed. The taps allow for a simple change, even after the machine is stocked, because they are brought out to a small terminal block and the whole thing only adds about $10 to the cost of the entire machine tool—a small premium for its manifold benefits. Twenty-five-cycle or 550-volt currents account for nearly another ten per cent but still have the transformer, with fixed ratio windings.

B. N. Foster (nonmember; Kingsbury Machine Tool Corporation, Keene, N. H.): We have read this paper over and agree with practically everything you say. Some of the points which you bring up are not of much interest to us personally and there are some points which you do not bring up which are of vital interest to us, but from our small knowledge of the subject you have covered the milling and grinding machine

situation very thoroughly and accurately.

I am a little bit sorry not to be able to offer some sort of constructive criticism here for I realize that your request for criticism was seriously made and that other viewpoints might be of use to you in your work with the committee. However, I can't think of anything offhand to talk about unless I get into a long discussion of some points not brought up in your paper which have no direct relation to the particular corner of machine tools which you are covering, and I don't know whether you would want this information at this time, and furthermore I don't know how we would have time to do this.

You realize, of course, that I am very much interested in the work which is being done by your committee in an effort to straighten out this entire electrical snarl and will be very glad to do anything I can to help. At present, however, the business conditions here do not permit me to spend very much time on matters of this sort. However, if specific points come up on which you would like to have me express an opinion, I would be only too happy to do so and would like to have you feel free to write me at any time on these matters and hope that I will be able to answer you satisfactorily.

G. H. Garcelon (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): I think you will find that manufacturers of industrial control keenly appreciate the problems encountered in machine-tool applications and are giving them considerable thought in their development programs. One characteristic difficulty is that several of the features required tend to increase the cost and size of the equipment which is, of course, directly opposed to the general desires of the machine-tool industry. You have cited items in your paper directly illustrating this point, as for example under the section titled "Certainty of Operation." There are several ways to secure greater accuracy in the time of operation and to decrease the possibility of failure to operate, but unfortunately all of them increase cost, size, or both.

In regard to the ease of changing the coils from 50 to 60 cycles you state that tests indicate that 60-cycle coils are fully qualified for 50-cycle operation. Normal 60-cycle coils and magnets are designed for an operating range of 85 to 110 per cent of rated voltage which is considered necessary to insure satisfactory operation. If these coils and magnets were designed to cover 50 cycles, as well as 60 cycles, it would be the equivalent of applying approximately 20 per cent greater operating range and this would necessarily mean larger and more expensive magnets and coils.

Some tests may indicate that commercial designs seem adequate for this range, but I am afraid that certain conditions have been overlooked. The operation may be satisfactory in the open or in a large enclosure, but the manufacturer must design these units so that they may also be operated in small enclosures which may represent an increase in effective temperature of the air surrounding the coil amounting to 20 to 30 degrees centigrade. The tendency of manufacturers is to design for a more conservative maximum temperature of coils than is permitted by the standards in an attempt to avoid coil failures after several years' operation under somewhat adverse conditions.

The percentage of 50-cycle applications is small and the coils are rather inexpensive, therefore the best solution of this problem would seem to be along the lines of making the designs such that coil changes can be made readily.

F. H. Penney (nonmember; General Electric Company): I am sure the manufacturers of electrical equipment are deeply indebted to Mr. Graves for his paper. It is at once evident that a great deal of painstaking thought has been given to the selection of the proper control units.

I would like to comment on the reference to the difficulties encountered because of the various voltages and frequencies found not only in the United States but abroad. Unfortunately it has not proved practical to permit the operation of magnetic switches through voltage or frequency ranges wide enough to warrant a dual voltage or frequency rating unless voltage and frequency vary in the same ratio and even then only to a limited extent. Size limitations and the normal voltage fluctuations encountered on standard power systems require about all the margin in design which can be built in and maintain the highly desirable features now provided without adding a range on top of this.

However, a scheme used on certain large panels and to some extent on smaller units offers one way toward the goal of a standardized panel for machines through the 50/60-cycle range with a voltage range from 200 to 550 volts. The inclusion of 50 cycles is particularly important because of the foreign business now coming to machine-tool builders.

The plan briefly is to segregate the control circuit entirely from the motor or power circuit by means of a transformer, selecting some standard control-circuit voltage such as 220 volts, 60 cycles. The transformer, it is true, adds something to the cost. However, the advantage is likely to be considerable where machines are produced in lots of 25 or more since all magnetic switches can be equipped with 60-cycle 220-volt operating coils. Only the overload relay heaters need await assembly when the order comes in specifying voltage and frequency.

The transformer primary equipped with taps can provide for the voltage range 208, 220, 440, 550, 60 cycles; the secondary voltage will remain 60 cycles 220 volts. Likewise if 50-cycle systems are to be provided for, taps are available primary and secondary whereby the correct voltage for 50-cycle operation can be secured. A small terminal board primary and secondary will make possible the correct connections of numbered terminals with very little time or trouble.

The transformer size need only be great enough to care for the maximum number of switches which will be energized at any given time. The cost is more than likely offset by the reduced spares and the reduction in delays occasioned by special coils, etc.

Mr. Graves also refers to the question of a suitable tape for use with Flamenol. This problem seems well along toward a solution and samples of a tape which will conform to the characteristics of Flamenol are being tried where oil and other compounds have made such a product a necessity. The preliminary reports indicate that very shortly a general distribution of the new product can be made.

R. S. Elberty (Landis Tool Company, Waynesboro, Pa.): Mr. Graves' paper is indeed a timely one. There is a growing field for electrical engineers in the machine-tool industry. The electric milling machine and electric grinder are excellent examples of the results obtained in applying good electrical engineering to machine tools. This subject has not received the attention it merits from electrical engineers in general or from the AIEE. Instead, we find such electrical subjects discussed by the ASTE, ASME, or the Machine Tool Electrification Forums held by Westinghouse.

Electrical drives must compete with mechanical or hydraulic devices that are well known to the average designer of machine tools. A. E. Rylander of the Midland Steel Company discusses "The Trend to Hydraulics" in the *Tool Engineer* for April 1939. The 1935 Machine Tool Show disclosed many advances in electric drives, but hydraulic drives had also developed rapidly. In 1939 we shall probably see more evidence of the very keen competition between hydraulic and electric drives.

The electric drive offers many advantages to the machine-tool designer. We have our troubles, as Mr. Graves outlines, but the electrical manufacturers have always been very helpful in developing and applying equipment to meet our needs. Our problems are specific and individual depending on the type of machine tool to which the drive is applied.

Many of my friends have suggested the formation of a society of machine-tool electrical engineers. I do not favor such a move. We can get together on electrical problems through some one of the existing engineering organizations. Perhaps this paper of Mr. Graves will bring about an aroused interest in machine-tool electrification among electrical engineers in general. Certainly there is room right in the AIEE for more papers of this nature.

B. P. Graves: In reply to P. H. Wilmarth's discussion on the paper entitled "Electrical Equipment on Machine Tools" I would like to say that we have done this in the past, although our control voltage is usually twice as high, namely, 220 volts on 60 cycles, and 187 on 50 cycles.

The objection raised is that it makes it more difficult for foreign users to obtain coils, that is, they can sometimes obtain 220-volt 50-cycle coils, but not 220-volt 60-cycle coils.

Because of this difficulty in obtaining 220-volt 60-cycle, we have refrained from using the transformer.

In reply to G. H. Garcelon, I would like to state that the reason that this subject of 50/60 coil was put into the paper, was to bring out the various difficulties and possibilities along this line. If this feature could be accomplished, it would be a material saving in our estimation, to machine-tool builders, and of course we in the ma-

chine-tool industry will have to be governed by the various opinions of the manufacturers of controls.

Our reason for suggesting this thought was the fact that we have been so successful in the use of 50/60-cycle motors.

In reply to the discussion as entered by F. H. Penney of the General Electric Company—there are several points in Mr. Penney's discussion which are of considerable interest, on some of which I feel I would like to express my opinion.

In reference to the difficulty encountered because of the various voltages and frequencies found not only in the United States, but abroad, I rather take exception to Mr. Penney's remarks when he says it has not proved practical to permit operation of magnetic switches through voltage or frequency ranges wide enough to warrant a dual voltage or frequency rating. This has been an argument for sometime among the electrical manufacturers, but now we find one company which has agreed to our plea and in starting this dual-voltage arrangement, several other companies are now following, and this is proving to the machine-tool industry a big saving, both in time and patience. I feel that with a little further study, all control manufacturers will follow along this line.

In reference to adding a transformer, I feel that the general idea is good, and some day we may feel obliged to follow this practice, but it does increase the difficulty of foreign purchasers obtaining a correct supply of 60-cycle 220-volt operating coils. This is one of the points that has been brought up to our attention on many occasions by foreign purchasers.

In reference to suitable tape for use with Flamenol, I am pleased to state that since the meeting we have received two large sample rolls and at the present writing this tape looks exceedingly good to us and may be the means of solving one of our very annoying problems.

In reply to Mr. Elberty's discussion on the paper, there is very little that I can say other than to agree thoroughly with the points that he has brought out.

In reference to the point of machine-tool builders having to compete with mechanical and hydraulic devices, I think this is a point well taken as in my opinion, the electrical companies don't seem to realize that this is a matter that must be most thoroughly investigated by the average designer of machine tools, because it is very imperative in bringing out a new design that it should be in very close alignment with competitive machines, both for price and features.

Regarding the point of designing electric drives and the electrical manufacturers having been very helpful in developing and applying equipment to meet our needs, because of the fact that our problems are specific and individual, depending on its type. This is one of the reasons why it is becoming much more difficult for electrical companies to do the engineering for the machine-tool manufacturers, but I do feel that it should be possible for us to get together with electrical manufacturers, more especially now that we machine-tool builders are inclined to consider the electrical end as part of our daily work, and in tying our two organizations together, to bring about much more interest in the electrification of machine tools.

Modern Trends of Low-Voltage Air Circuit Breakers

J. W. SEAMAN
ASSOCIATE AIEE

Synopsis: The history of low-voltage air circuit breakers has paralleled the development of power distribution. The desire for improved contacts led from an automatic knife-switch type of circuit breaker to an air circuit breaker equipped with a laminated copper brush. The trend from d-c systems to polyphase a-c systems led from the "nontrip free" type of air circuit breaker to the "trip free" breaker; and now the requirements for low maintenance, safety of operation, increased continuity of service, together with the trend to steel enclosing of switchboards and individual devices, is being met by new air circuit breakers equipped with solid silver main contacts, alloy arcing tips, and a new type of arc interrupter herein described.

THERE has been a considerable change in air-circuit-breaker construction during the past several years, due principally to the increased requirements for low maintenance, safety of operation, and increased interrupting ability. In order to emphasize the recent improvements, a review is made of the history of air-circuit-breaker construction.

The first device, which may be classed as an air circuit breaker, was little more than an automatic knife switch. This device probably originated about 1885. Figure 1 illustrates a typical breaker of this construction. Two fundamental requirements, which we have to this day, were met by this device, that is, an operable contact member to open and close an electrical circuit, and an overcurrent trip responsive to abnormal circuit conditions. The movable contact blade was held in the closed position by a mechanical latch that could be released by the overcurrent trip thus causing the opening of the blade and consequent interrupting of the circuit. Secondary contacts of carbon and copper were utilized with this type of device to take the burning on opening and closing of the circuit.

The next major step occurred about 1892 and dealt with the current-carrying ability of air circuit breakers. At this time we find the knife-blade type of contact being superseded by a laminated-brush contact. Improved secondary contacts were also provided for protecting the main current-carrying contacts during opening and closing of the circuit. Figure 2 shows a typical device of this period. This construction was a distinct improvement for carrying current continuously, largely due to the wiping action of the several laminations employed in the main contacts.

Also during this period the first air circuit breakers utilizing a magnetic-blowout chute were produced in answer to the demand for a satisfactory breaker for the many d-c railway projects then active. Figure 3 shows a typical breaker of this period equipped with such a chute.

The three-phase a-c system appeared during this time. A-c motors and other connected devices were then quite small and easily controlled, so that it was not

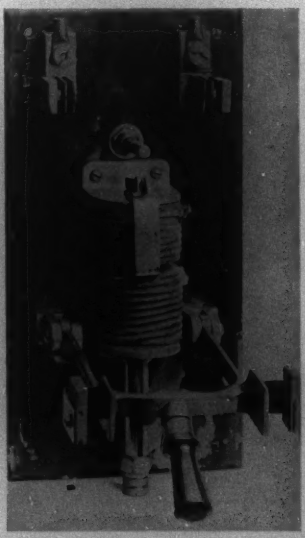

Figure 1. Knife-switch type of air circuit breaker

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until 1905 that the increase in the size of such systems required suitable a-c air circuit breakers. The development of three-phase breakers brought the first real regard for safety of operation. Prior to this period, air circuit breakers for d-c service had been what was popularly called "nontrip free," that is, the operating handle was definitely tied mechanically to the movement of the breaker contacts, and as a result it was possible for operators to hold such breakers in against a severe overload merely by holding the handle in the closed position. As can be readily appreciated, the closing of a breaker of this type against a severe overload or short circuit could readily result in disastrous consequences. The generally accepted procedure for coping with this situation was to utilize a switch in series with the circuit breaker, which could be closed after the circuit breaker had been latched in, thereby permitting immediate opening of the air circuit breaker if the switch was closed against abnormal circuit conditions. To eliminate the necessity for such switches, the so-called "trip free" breaker was generally adopted. With an air circuit breaker of this type, closing against abnormal circuit conditions results in the operating handle being disengaged mechanically from the movable contact structure, rendering impossible

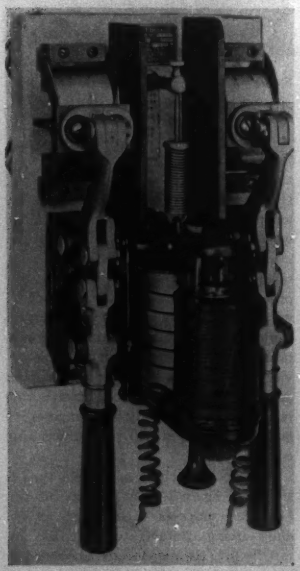


Figure 2. Early breaker with laminated brush

Figure 3. Early magnetic-blowout air circuit breaker

the holding in of the breaker under abnormal circuit conditions. Breakers of this type were first brought out around 1905, and as illustrated in figure 4, formed the basic model for all air circuit breakers manufactured during this period up to approximately 1930. The similarity in construction can be readily appreciated by comparing the air circuit breaker shown in figure 4 with the one illustrated in figure 5.

This résumé, while very brief, covers the general improvements up to date. The major contributions to the art appear to be the development of the laminated-copper-brush contact and the trip-free type of mechanism. The use of carbon-tipped arcing contacts which separated in air provided the means for arc extinction. Figure 5 illustrates the type of air circuit breaker in general use in 1930 and in some instances, with minor modifications, still available commercially.

Modern Air Circuit Breakers

In the light of what has transpired in the years prior to 1930, the trend of the past eight years is worthy of note. During this period satisfactory answers to the demand for low maintenance, increased continuity of service, greater safety, and improved current-interrupting performance have become increasingly important. A considerable premuim has also been placed upon such physical factors as space requirements and weight. The

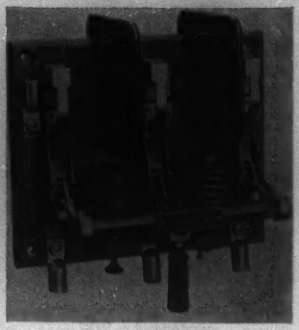


Figure 4. Early trip-free air circuit breaker

work done during the past several years has, we believe, satisfactorily answered and met most of these modern requirements.

Contacts

The first requirement to meet, and the most important at the time, was developing main current-carrying contacts which would require relatively little maintenance and insure the greatest continuity of service. The main contacts utilized prior to this period were of the laminated-brush construction, each lamination consisting of a piece of spring copper. While these contacts were generally satisfactory, it is necessary to acknowledge that copper, in itself, has undesirable oxidation characteristics. If through poor maintenance copper oxide is allowed to form on the contacts, cumulative heating is carried to the point where the spring copper laminations are annealed and the service impaired or interrupted.

Also, the increasing development of industrial processes which involved intermittent circuit overloads as a normal part of the processing cycle made it desirable to develop a contact which would withstand overheating that might cause the laminated-brush type of contact to fail.

After many laboratory tests on numerous materials, pure fine silver was selected as the contact material which would satisfactorily solve these problems. Silver stood out among the materials tested, primarily because of its low contact resistance and stability. Relatively little oxidation occurs on silver. This oxide breaks down at comparatively low temperatures and pressures. Copper oxide on the other hand is mechanically tough and requires rather high temperatures to break it down.

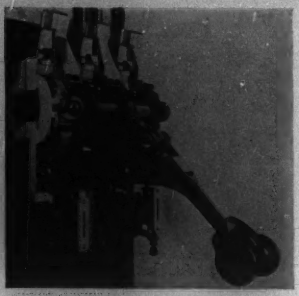


Figure 5. Trip-free type of air circuit breaker, manufactured in 1930

Figure 6 shows a typical contact construction employing fine silver blocks for the main contact surfaces. Contact pressure is obtained by a separate compression spring not in the current circuit. As may be appreciated, a contact of this type may be subjected to severe overload conditions without impairing its current-carrying ability. As may be noted the silver blocks on the movable contact have a convex surface to obtain a line contact. This utilizes efficiently the pressure of the contact spring and assists in breaking down the silver oxide that may form. Figure 7 furnishes a comparison of the physical size of a laminated copper brush and a silver-faced contact of the same current rating. The considerable reduction in size, obtained by the use of silver, has contributed materially to the building of more compact breakers as well as reducing the interrupting time due to the lowering of the inertia of the movable-contact structure. About eight years of field experience with this type of contact has been obtained with very satisfactory results. Following this favorable experience, all of our modern air circuit breakers have been equipped with this type of contact.

Similar work has also been done on improving the arcing contact structure associated with the main current-carrying contacts. The use of alloys which have a much lower resistance than the carbon materials formerly employed and also greater mechanical strength provides the greatest improvement in this particular phase of construction. These alloys permit much better current transfer from the main contacts during arc interruption than was formerly enjoyed.

Interrupting Units

The next problem dealt with the necessity for handling large blocks of power, due to the substantial increase in the short-circuit capacity of a-c systems. Until recently, no particular attention had been paid to the interrupting capacity of air circuit breakers as the connected capacity was generally small. A listing of interrupting ratings for low-voltage air circuit breakers was published on May 26, 1938, by the large-air-circuit-breaker group of the National Electrical

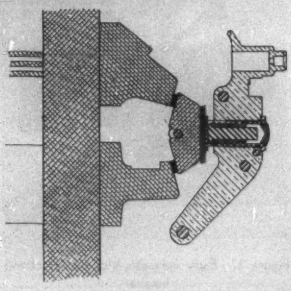


Figure 6. Typical silver-contact arrangement

Manufacturers Association under section *SG*-7-26 and is the first generally recognized list of air-circuit-breaker interrupting ratings. It had been generally considered that in low-voltage a-c systems it would be impossible to get short circuits of much more than 20,000 amperes. However, in recent years increased system capacity and larger industrial processes have resulted in the possibility of obtaining short-circuit currents of the order of 60,000 to 80,000 amperes, and in some instances even higher. Thus the necessity of air circuit breakers with adequate and proved interrupting ratings. This, coupled with the fact that in the interest of safety and low cost of installation, there has been a considerable trend toward factory-built steel-enclosed switchboards and steel-enclosed individual breakers, necessitated a considerable study for adequate and safe means of controlling high-power arcs.

While prior to 1930 considerable work had been done on arcs in oil, relatively little had been done concerning the study of high-capacity arcs in air. It is granted, of course, that the addition of arcing contacts to air circuit breakers, as shown in figure 5, would considerably increase the current-interrupting ability of air circuit breakers, particularly if considerable head room above the arcing contacts is provided. In addition to this, the magnetic-blowout chute, as shown in figure 8, is adapted to interrupting large amounts of currents if no difficulty in the nature of adequate air space over the top of the chute is encountered. As a matter of fact, the device, as shown in figure 8, equipped with magnetic-blowout chute has satisfactorily interrupted currents of the order of 330,000 amperes root-mean-square in a remarkably short time, as is illustrated in figure 9. Such a test demonstrates very clearly the rapidity with which currents of such magnitude can be completely extinguished. It is not feasible, however, to apply such breakers in the limited compartments associated with steel-enclosed air circuit breakers, the reason being that inadequate head room will greatly impair the interrupting ability of such a device. The satisfactory handling of currents of large magnitude in small steel compartments, therefore, greatly complicated the problem of developing a suitable arc interrupter which would be applicable over a wide range of interrupting ratings. After investigating several different ways of attacking this problem, the "pin-type arc quencher" was decided upon as the type of interrupter most generally applicable to a wide range of interrupting ratings. This device has now been successfully applied to air circuit breakers whose interrupting ratings range from 10,000 amperes to 80,000 amperes, at 600 volts alternating current.

Figure 7. Size comparison of solid-silver contact and laminated-copper-brush contact

A typical arc chute of the pin type is shown in figure 10. A pair of soft-iron U-shaped magnets is attached to the alloy arcing contacts to drive the arc rapidly into the pins located above. The pins are positioned with respect to each other so as to develop the maximum volt-

age gradient. As the arc is driven into the pins it is broken into a series of arcs which travel through the pins until extinction is complete. Located above the pins is a series of baffles spaced apart so as to provide a series of narrow slots through which the gases generated by the arc escape. The width of each slot is proportioned so that the arc itself is confined within the chute. This, coupled with the cooling of the arc gases in traveling through the slots, eliminates the possibility of the arc striking to nearby grounded metal parts. The extinction of the arc is due primarily to two reasons—first, to the voltage gradient obtained from the sum of the cathode drops of the series arcs, and second, to the effective projection of the arc against efficient cooling surfaces resulting in rapid deionization of the arc stream.

The chart illustrated on figure 11 gives a comparison of the arcing times of a conventional open-break type of air circuit breaker tested without an enclosure and an enclosed air circuit breaker equipped with "pin type" arc quenchers. It may be noted that the arcing time of the former is quite erratic even when tested in the open, where the enclosed "pin type" breaker interrupts consistently over a wide current range in two half cycles or less. Operation of this sort greatly reduces the stress on the equipment to be protected and contributes materially to the safety of the operating personnel. Table I shows data from interrupting tests conducted on a 6,000-ampere air circuit breaker, equipped with pin-type arc quenchers, at 600 volts, three phase, up to and including a maximum current of 125,000 amperes. It is to be noted that the arcing times are one-half cycle or less, and indicates definitely the consistent performance of this type of interrupter. Figure 12 shows an oscillogram of the maximum current interrupted during this particular test series.

Table I. Data From Three-Phase Tests on a Type AL-2, 6,000-Ampere Air Circuit Breaker Equipped With "Pin Type" Arc Quenchers

Duty—O_1 Test—600 Volts, Three Phases, 60 Cycles

Current (Amperes), Maximum Loop		Duration of Short Circuit (Half Cycles)	Arc Duration (Half Cycles)
Peak Value	Root-Mean-Square Value		
52,000	30,000	7.0	0.9
59,000	34,000	7.1	0.7
79,000	46,000	7.1	0.7
103,000	62,000	6.4	0.5
128,000	76,000	6.7	0.9
83,000	50,000	6.7	0.7
125,000	76,000	6.0	0.8
116,000	78,000	6.4	0.8
137,000	80,000	6.4	0.7
166,000	100,000	6.0	0.8
245,000	142,000	5.9	0.5
192,000	114,000	5.8	0.7
192,000	119,000	5.5	0.7
210,000	134,000	5.7	0.7
220,000	130,000	5.6	0.6

In figures 13 and 14, typical breakers equipped with pin-type arc quenchers for interrupting ratings of from 10,000 to 80,000 amperes are shown. The introduction of such devices constitutes a major step in the art. Experience during the past three years, since these interrupters were introduced to the field, has indicated a very satisfactory performance. Needless to say, due to the efficient way in which these interrupters control the arc, outward objectionable disturbances such as noise, hot arc gases, and other volatile arc products have been greatly reduced, so much so that typical steel-enclosed breakers of this type manifest no outward disturbance even when tested at their full interrupting ratings.

General Structure

Figure 15 illustrates a more recent trend of air-circuit-breaker construction. Heretofore, the majority of air circuit breakers have been of the manually operated type. Recently, however, there has been a decided increase in the use of air circuit

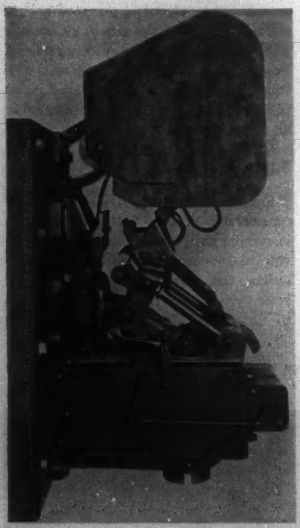


Figure 8. Modern magnetic-blowout type of air circuit breaker

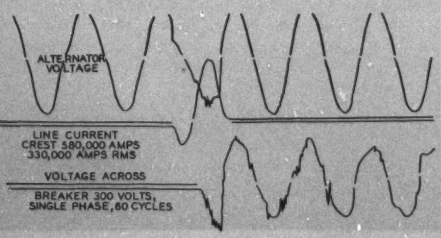


Figure 9 (below). Oscillogram of high-current test on modern magnetic-blowout type of air circuit breaker

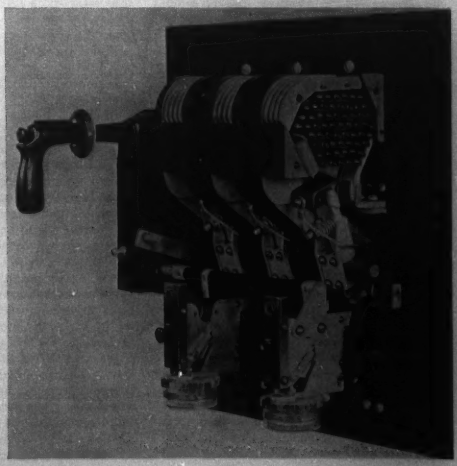


Figure 10. Typical pin-type arc-quencher construction

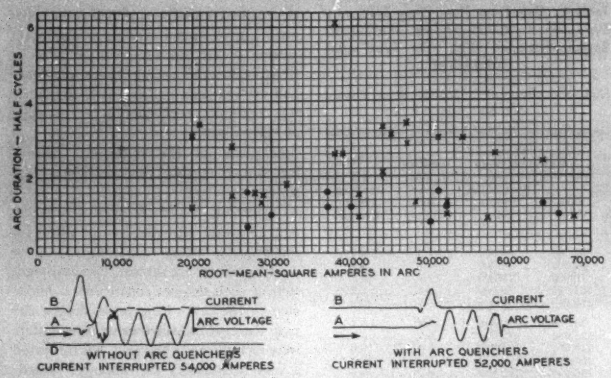


Figure 11. Comparison of arcing times on an open-type carbon-break air circuit breaker and an enclosed air circuit breaker equipped with pin-type arc quenchers

Type AL-2 air circuit breaker, 600 volts, 1,200 amperes, interrupting rating 40,000 amperes

Crosses—Tests at 600 volts, single phase, plain break, open

Circles—Tests at 600 volts, single phase, with arc quenchers

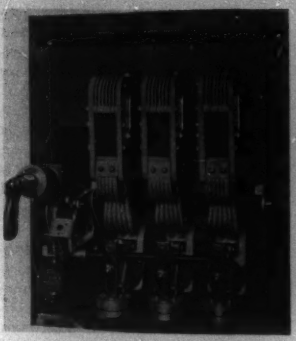


Figure 13. Modern small air circuit breaker equipped with pin-type arc quenchers

breakers which can be operated satisfactorily from a remote point. The generally accepted practice for coping with such a requirement has been to equip an air circuit breaker of the manually operated type with a separate electrical mechanism which, while perfectly satisfactory from an operation standpoint, requires a considerably larger space for mounting. As this trend is associated, however, with the increased use of steel-enclosed air circuit breakers, it is obviously a considerable handicap to increase the size of such steel enclosures merely to provide the necessary additional room for the electrical operating mechanism. To meet this demand without sacrificing space, there has been developed the air circuit breaker structure as shown in figure 15. These latest air circuit breakers require exactly the same space for either manual operation, or electrical operation. This is obtained by simply applying either a suitable manually operated unit or electrical operated unit to the main body of the air-circuit-breaker mechanism. As can be readily realized, this type of construction has met with considerable favor in the field and is, we believe, indicative of the general trend in all future designs.

Summary

From the foregoing, it is evident that considerable progress has been made in increasing the general usefulness of low-voltage air circuit breakers. We have described the evolution from an adapted knife-switch device up through the years to the present-day air circuit breakers

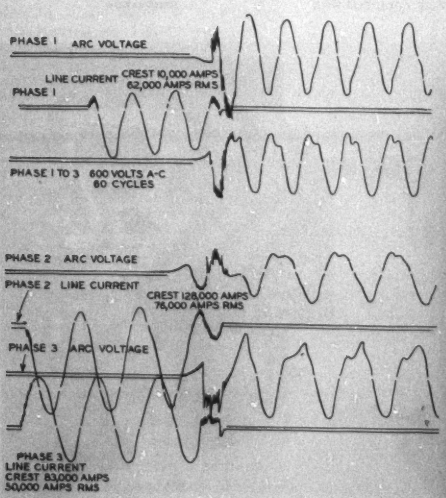
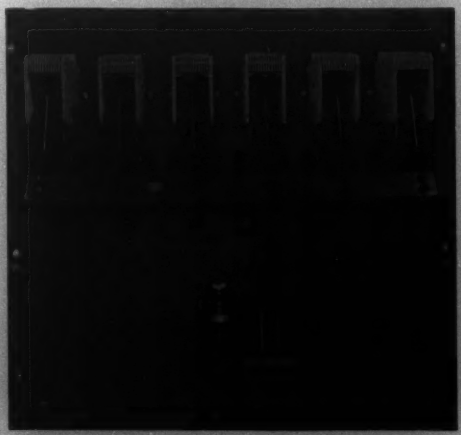


Figure 12. Typical oscillogram of an interrupting test on a 6,000-ampere air circuit breaker equipped with pin-type arc quenchers

Figure 14. Modern large air circuit breaker equipped with pin-type arc quenchers



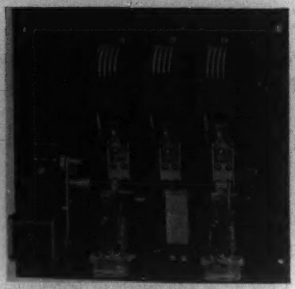


Figure 15. Modern electrically operated air circuit breaker

applicable to all low-voltage power and lighting circuits where continuity of service, safety of operation, and low maintenance are desired. The development of the solid-silver line-contact construction has contributed materially to the increased speed of operation, reliability of service, and reduction of size which are such paramount factors today. The pin-type arc quencher is a material contribution to the safety of personnel and protection of equipment, and its performance renders possible the use of air circuit breakers in steel-enclosed compartments without impairing the interrupting ratings.

Discussion

A. E. Anderson (General Electric Company, Philadelphia, Pa.): Mr. Seaman has described certain developments that have taken place in order to produce low-voltage air circuit breakers having improved performance features, such as low maintenance, improved current-interrupting performance, together with reduction in weight and space requirements.

Any improvement in the design of the main current-carrying parts, which will result in reduced maintenance and increased continuity of service, is a step in the right direction. However, the question frequently arises as to the necessity of circuit breakers of interrupting ratings in excess of 40,000 amperes. A rule of thumb that has been quoted many times is that it is difficult, if not impossible, to obtain currents in excess of 20,000–40,000 amperes on circuits up to 600 volts alternating current, due chiefly to the presence of contact or arc resistance. Experience has shown that it is possible to obtain currents in excess of this value.

Outside of machine characteristics, the factor of resistance is the only one that appears in connection with d-c circuits and there seems to be no question that very large currents are possible and values in excess of 200,000 amperes at 600 volts have been obtained. The resistance found in such circuits during fault conditions is exceedingly low. Accordingly, due allowance has been made in selecting circuit breakers for such applications.

As far as a-c circuits are concerned, we must consider in addition the reactance of the external circuit and that of the generating or transformer equipment. The per-unit reactances of low-voltage generators are usually considerably less than those in the higher-voltage machines, thus tending to increase proportionately the value of short-circuit current. Also, the reactance of low-voltage conductors is less than that of higher-voltage conductors due to decreased spacing. Looking at this from the voltage-regulation standpoint, it would be expected that the allowable maximum regulation would not exceed ten per cent for satisfactory operation of motors and other apparatus. Accordingly, the short-circuit current available at the time that the circuit breaker opens would be at least ten times the continuous-current rating of the circuit. This result takes into consideration the circuit resistance as well as the circuit reactance.

In the case of switchgear, the maximum short-circuit current is obtained in the vicinity of the circuit-breaker terminals, which means that only the connection copper, busses, cables, and other primary circuit apparatus between the point of short circuit and the generator or transformer should be taken into consideration. Generally speaking, less than ten per cent of the total impedance of this part of the system is found in the cable or apparatus external to the generator or transformer. In fact, this impedance is usually so low that it can be neglected. A further consideration shows that the resistance component of this impedance has a minor effect on the calculated result. The use of silver at the various points of contact in the switchgear, further tends to reduce this factor. Faults some distance from the switchboard, such as at the end of feeder cables, or at some group bus supplying motors or other apparatus, will usually result in lower short-circuit current due to the relatively higher impedance of these smaller cables.

This then leaves the item of arc resistance and its contribution to the over-all result. An open arc is a random affair. Mr. Seaman's paper brings out the design features in a circuit breaker that have to be taken into consideration in order to control the arc and keep it confined within a restricted space.

As the installation becomes larger, a greater amount of short-circuit current is developed and a greater space would be required for the interruption of any free or open fault arc. The spacing of conducting parts at the rear of the switchboard does not permit this arc to expand to the extent that its resistance would have an appreciable effect, or to reduce the current to one-third or one-half of its calculated value, which would sometimes be required in order to limit its value to 40,000 amperes as mentioned above. Therefore the effect of resistance of any open or free arc that might be obtained on the circuit is omitted in calculating the short-circuit current.

The mechanical and thermal requirements of current transformers, connection copper, and associated apparatus must also be taken into consideration. For example, the bus may not only be required to have a rating as high as 10,000 amperes, or more, but may have to withstand stresses imposed by fully offset values greater than 200,000 amperes root-mean-square. This part of the application brings in the stress set up by the electromagnetic forces, coupled with vibration at fundamental and harmonic frequencies, due to resonance between bus, supports, and the frequency set up by the electrical system.

Modern practice calls for an enclosed type of circuit breaker. This feature provides a safe and compact installation and, in one variety of switchgear, a design that permits ready means for withdrawing the unit for inspection or maintenance. The circuit breaker is so interlocked that it must be in the open position before it can be connected to or disconnected from the bus. The smaller units are arranged vertically, usually three high. The larger and heavier units are mounted on one level only and rolled into position.

Units of this kind have been applied to motor, generator, transformer, lighting, station auxiliaries, and other loads. Provisions are included to facilitate shipment and installation, as well as to permit future expansion. The latter possibility should include a consideration of the maximum amount of generating or transformer capacity in order to meet the short-circuit requirements that may arise in the future.

D. C. Prince (General Electric Company, Philadelphia, Pa.): From time to time the question has been raised whether it is necessary to have interrupting ratings of air circuit breakers of the order of 40,000/60,000 amperes or more where these circuit breakers are installed on 440- or 600-volt circuits. It has been contended that even though calculations might show such currents could exist, actually in practice they would not, and, therefore, discount factors have been employed, and smaller circuit breakers have been installed than those bearing the ratings of the calculated maximum short circuit. There was a feeling for some time that for some reason or other short circuits actually obtained did not correspond to calculated values. In the last year or two a good deal of work has been done along this line, taking great pains to include in the calculation allowance for all available reactance and resistance, and it is now certain that where the calculation is made with sufficient care, the currents for a bolted short circuit will correspond very closely to the calculations.

The next question raised is whether an actual short circuit occurring in the field may have the properties of a bolted short circuit. It goes without saying that most short circuits will not have such properties. Particularly in calculations involving control apparatus, the short circuits are likely to include considerable cable runs, and when a breakdown does occur, such as between winding and ground in a motor, the fault is likely to have a considerable amount of impedance.

On the other hand, where a switchboard is involved, any fault occurring in the switchgear structure may approach the full value of a bolted short circuit. The question has been raised whether a foreign body such as a copper bar will not be blown clear, say from a bus structure across which

it has fallen, without giving currents of greatest magnitude. Tests of this particular configuration have been made with the result that currents of the order represented by the circuit breaker ratings will blow a solid bar clear but not quickly enough to prevent the current from reaching its maximum value. Even in the switchboard structure, most faults are likely to have less value than the maximum calculated fault. For instance, a short section of control wiring getting across the busses will be fused almost instantaneously and may produce an arc of sufficient length to keep the current well below the maximum possible fault. However, if the calculation has been carefully made, it is certain that the maximum fault current calculated may occur, and for that reason air circuit breakers should be installed with ratings equal to or greater than the maximum calculated fault if it is necessary to be sure that the fault will be cleared by each breaker in question.

In considering the application of air circuit breakers, however, there is one more point which should be covered. If an oil circuit breaker is incorrectly applied and is stressed beyond its capacity and fails to clear, serious damage may result. The circuit breaker may burst, allowing the escape of oil, which may produce secondary damage of considerable magnitude in addition to the loss of the breaker itself. An installation of oil circuit breakers under conditions where the maximum fault is known to be beyond the circuit breaker capacity may represent a real hazard and not merely a business risk. On the other hand, if an air circuit breaker is placed in a circuit where the maximum possible short circuit may exceed its interrupting ability, the circuit breaker itself may be burned up, but secondary damage is likely to be of a relatively minor character.

It has been found that where a number of small circuit breakers are backed up by one larger one, which is free to trip instantly in the event of a heavy short circuit, the cascade combination will satisfactorily clear a fault up to the capacity of the larger circuit breaker. Tests have been made to verify the range in sizes for which the smaller breaker will be protected. With these factors in mind, it is possible to design a distribution system including various sizes of air circuit breakers, the smallest of which are of a rating less than the maximum short circuit which they may be asked to clear. In the unlikely event that such a short circuit does occur, it should not be necessary to replace the particular small circuit breaker involved, but even if the smaller breaker is damaged, this may be regarded as a legitimate business risk. In such an installation, of course, there must always be some circuit breakers of adequate capacities to take care of any fault which may possibly occur, and of adequate speed of operation to afford some real protection to the smaller breakers. Air circuit breakers are available which have these characteristics, proved by actual tests, both free and in enclosures, sufficient to meet the most exacting demands.

In past times, the application engineer has faced the dilemma that if he recommended large enough capacities to be safe, his installation was uneconomical, while a recommendation, sound from an economic point of view, was hazardous to both life and property. With knowledge of the new air circuit breakers, he can, by suitably selected and proportioned backup protection, secure a practical solution of this problem. Small air circuit breakers protect utilization equipment from all but the exceptional faults at a minimum of cost. Master breakers of adequate rupturing capacity back up the first line and protect both equipment and small breakers from the exceptional fault.

Special Problems of Two-Pole Turbine Generators

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THE two-pole turbine generator differs from similar generators with a higher number of poles, in that the mechanical rigidity of the rotor body varies from a maximum value on the pole axis to a minimum value on the winding axis, and the stator core is subjected to radial magnetic forces on only one diameter corresponding to the axis of the resultant magnetic field.

The unequal mechanical rigidity of the rotor body on the two major axes results in a variation in the static deflection of the rotor as it rotates. This variation in the deflection occurs at a frequency equal to twice the rotating frequency and acts as a double-frequency vibratory force in causing the rotor to vibrate.

The unequal magnetic forces on any two major axes of the stator core cause it to distort and take an elliptical shape, with the short axis of the ellipse coinciding with the axis of the air gap magnetic field. The distorting magnetic forces rotate with the rotor and thus produce a stator core distortion which rotates at synchronous speed. Since the elliptical shape rotates with the rotor, the resulting vibratory motion of any point on the stator core has a frequency twice that corresponding to the rotating speed.

These rotor and stator double-frequency vibratory forces and resultant vibrations are present in every two-pole generator irrespective of rotational speed or physical proportions. The vibration is more pronounced in the case where the frequency of the forces is approximately equal to the resonant frequency of the part in question. The effects are relatively small in 25-cycle units due to the fact that the frequency of the disturbing forces is low with respect to the resonant frequency of the generator and foundation parts. They are also negligible in small-capacity 3,600-rpm generators because of the relatively small double-frequency magnetic forces involved. Double-frequency stator vibrations have been observed on two-pole 60-cycle generators for ratings of 18,750 to 20,000 kva. Both types of double-frequency vibrations become of increasing importance for 60-cycle 3,600-rpm units of relatively large capacity. In such units of larger capacity, the double-frequency vibratory forces are transmitted to mechanically connected associated apparatus, bearing supports, foundations, and station structural parts, and result in objectionable vibrations and noise.

It is the purpose of the present paper to discuss the general problems of double-frequency rotor and stator vibrations of two-pole generators and present methods by which the disturbing force producing the vibration can be eliminated or the vibration restricted to specific isolated parts.

Double-Frequency Rotor Vibration

The general problem of 3,600-rpm-generator double-frequency rotor vibration due to unequal mechanical rigidity on the two major axes of the rotor was investigated by the writers in 1928 and 1929. Rotor models, dynamically similar to the rotors for the largest 3,600-rpm generators which were then contemplated for the future, were made. Running tests were made on the models over a speed range from zero to 4,500 rpm, and vibration measurements were made for

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the entire speed range. The following facts were obtained:

1. The models vibrated with quite large amplitudes at rotating speeds corresponding to one-half their fundamental natural frequencies. The frequency of the vibration was twice that of the rotation of the models.

2. The double-frequency vibration persisted throughout the entire speed range and it was not influenced by changes in the balance of the models.

3. The models were found to have two fundamental natural frequencies corresponding to the two principal rotor rigidities. These critical frequencies were about 50 rpm apart and were less than one-half the normal operating speed of 3,600 rpm. The vibration of the models throughout this 50-rpm speed range was unstable, that is, the amplitude of vibration would steadily increase when the speed was held constant.

4. The single-frequency vibration predominated throughout this 50-rpm speed range and over this speed range the models were quite sensitive to the amount of unbalance present.

The following conclusions applying to large-capacity 3,600-rpm generators were reached from a study of the data obtained from the model tests:

1. The internal damping in the rotor body of an actual generator due to the friction of the conductors on the coil slot sides was considered to be sufficient to ensure stable operation of the rotors throughout the total speed range.

2. Rotors of the length in question were known to be more difficult to balance than the shorter, more rigid ones, but it was thought that with proper care being given to the placing of the balance weights along the axis of the rotor, the job could be done without difficulty.

3. It was realized, before the model tests were made, that the double-frequency vibration would persist throughout the speed range of the rotor, but no trouble with it was anticipated because of the great difference in speed between one-half the first critical speed and the normal operating speed.

Since these tests were made, 3,600-rpm turbine generators have been built with conventional rotor designs for ratings of 43,750, 50,000, and 58,750 kva. The running performance of the rotors of these generators has demonstrated the accuracy of our predictions as based on the model tests. In no case did any of the above rotors give evidence of instability or excessive vibration at either the fundamental critical speed or at the subcritical speed equal to one-half the fundamental. The rotors were more difficult to balance, but with the more accurate balancing equipment now available, this was accomplished satisfactorily. Two of the above rotors were entirely satisfactory in regard to double-frequency rotor vibration at full speed. The magnitude of the double-frequency vibration in the rotor of the 58,750-kva generator, although acceptable, was somewhat higher than originally anticipated. Corrective action may be taken on this rotor at a future date to reduce the magnitude of the double-frequency vibration.

It was originally anticipated that two-pole 60-cycle generators above 62,500 kva would necessitate changes in the rotor design adequately to take care of the double-frequency forces and vibrations

A first natural suggestion might be to provide flexibility in the bearing supports so that the vibratory forces would not be transmitted to the foundation, station parts, and other equipment. This type of corrective measure can be considered to be only partial solution at best, even though it were 100 per cent effective, since it permits the rotor shaft ends to move freely and thus transmit the double-frequency motions to the collector rings, couplings, and coupled apparatus. The effects of double-frequency vibrations on these parts are of equal or greater importance than on foundation and station equipment.

A second and more fundamental method of solving this problem is to equalize the mechanical rigidity on the two major axes and thus reduce the double-frequency disturbing forces to values of inappreciable magnitude. There are two methods of equalizing the mechanical rigidity on the two major axes. One is to machine annular grooves in the rotor body to such depth that the additional rigidity contributed by the pole sectors and rotor teeth will be inappreciable. This is not a feasible method for two-pole 60-cycle generators due to the fact that the rotor diameters are inherently small and the provision of annular grooves of appreciable depth would result in an intolerable flexibility of the rotor. A second and more feasible method is to reduce the rigidity on the pole until it is essentially equal to the combined rigidity of rotor teeth and field coils on the winding axis. This can be accomplished by machining longitudinal or transverse slots in the pole body. If longitudinal slots are used, it is necessary to remove an appreciable percentage of the pole material to get the necessary change in rigidity. Thus, in order to avoid too much saturation and a reduction of the magnetizing flux in the pole body, it is necessary to replace the removed material with magnetic filler bars in the machined slots. The use of transverse slots in the pole body is the most effective method of obtaining a required reduction in rigidity with a minimum amount of material removed. Narrow, segmental-shaped, transverse

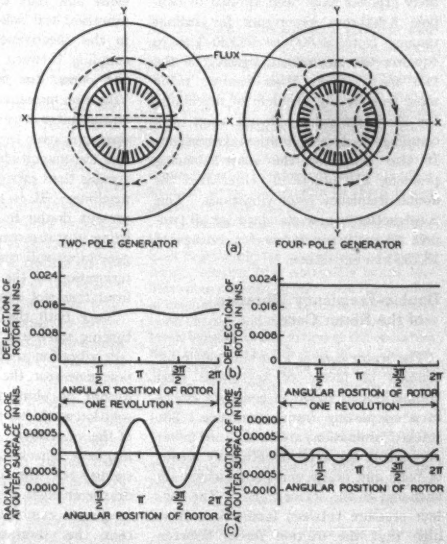

Figure 1. Diagrams illustrating comparison of two-pole and four-pole turbine-generator rotor and stator vibration

grooves can be provided in the pole body to accomplish the desired results without intersecting the winding slots and without removing an amount of magnetic material which would upset the magnetic saturation conditions. Both of these methods of equalizing the rigidity on the two major axes of two-pole generators are covered by United States Letters Patent number 1,994,922, which was issued in 1934.

Transverse, segmentally-shaped rotor body grooves have been applied to two-pole 3,600-rpm generators for ratings ranging from 20,000 to 58,750 kva to equalize the mechanical rigidity on the two major axes. This change made more feasible the problem of machining the shaft journals, collector rings, and couplings to true cylindrical dimensions. It also simplified the rotor-balancing problem, and practically eliminated the double-frequency rotor vibrations. This construction is now standard for all two-pole 60-cycle generators for ratings of 18,750 kva and above.

Double-Frequency Vibration of the Stator Core

The stator core of a turbine generator consists of layers of segmental steel laminations arranged in complete circles in a supporting frame structure. The stacked laminations are maintained under pressure in the axial direction by means of bolts and heavy end plates which are anchored to the stator frame. The contact pressure between laminations is so high that the friction forces between laminations are of such magnitude as to ensure that the built-up stator core acts as a solid steel cylinder in resisting distortion. The stator core is maintained in a fixed circumferential position with respect to the frame structure by means of dovetail keys or projections. Since the stator punchings are stacked in the stator frame with normal building clearances, it is obvious that the frame structure can contribute little or no rigidity to the stator core in resisting distorting forces. However, there is sufficient mechanical contact between the two members to permit the transmission of vibratory forces from the stator core to the frame structure.

There has been a wide variation in the amount of vibration and noise emitted from large-capacity 3,600-rpm generators of duplicate design and for units of different ratings, but using the same stator punchings. It is believed that the amplitude of vibration of the stator cores is essentially the same for all such cases and that the variation in frame vibration and noise is due to differences in the effectiveness of the mechanical coupling between the respective frames and cores, due to building variations. Vibration measurements have been made on the stator cores of such machines when operating over the complete load range, and the magnitude of the motions is no greater than experienced on lower speed machines. It is not believed that the present double-frequency vibrations existing in stator cores of two-pole 60-cycle generators will result in any undue deterioration of the stator core, winding, insulation, slot wedges, and main leads.

Since both the double-frequency disturbing force and the elliptical type of core vibration are inherent with the two-pole generator, the cause of the vibration cannot be eliminated. A first-thought solution would be to reduce the magnitude of the vibrations by reducing the air-gap magnetic density and by increasing the rigidity of the core to bending. If drastic changes were made in both items to give a combined change of 100 per cent, the vibrations would be reduced approximately 50 per cent and would still be transmitted in the conventional generator to the stator frame, foundation, and other station parts. The cost of the generator would be increased approximately 75 per cent and the manufacturer and purchaser would both still be confronted with the problem of determining whether a 50 per cent reduction in the amplitude of the vibration would be satisfactory. On the basis of the present data and operating experience available on large two-pole 60-cycle generators, it is felt that the results obtained would not be acceptable and the generator could not be justified economically. Since the magnitude of present stator-core vibrations is not considered deleterious to the life and performance of the generator, a more logical and economical solution would be to isolate the stator core and reduce the magnitude of the disturbing forces transmitted to other parts.

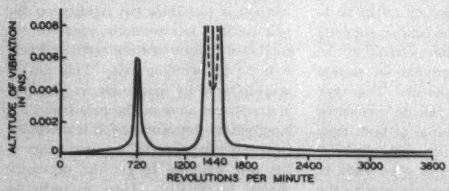

Figure 2. Vibration curve of unsymmetrical rotor

A mathematical analysis was made by J. G. Baker, formerly of the research department, Westinghouse Electric and Manufacturing Company, to determine the motion of any point in a freely supported two-pole turbine-generator stator core when subjected to a rotating diametrically applied distorting force. The

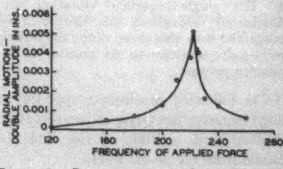

Figure 3. Resonance curve for stator core

essential results of this analysis are as follows when considering the stator core as a curved beam:

(*a*). The path of a point on the neutral axis of the stator core is an ellipse, the major axis of which is radial and twice the length of the minor axis.

(*b*). For points at a larger radius than that of the neutral axis, the tangential motion decreases as the radius is increased. At a distance beyond the neutral axis equal to one-third the radius of the neutral axis, the tangential motion is zero, and the motion is purely radial.

(*c*). For points at a shorter radius than that of the neutral axis, the tangential motion increases as the radius is reduced and the path of a point in the tooth zone is approximately circular.

(*d*). The maximum change in the dimensions between adjacent teeth is only 10 to 15 per cent of the radial motion at the back of the core.

In order to check the calculated characteristics of the stator-core vibration and determine methods to prevent the transmission of vibratory forces from the stator core to other parts, a complete experimental investigation was made on a full-size generator model. The model consisted of a stator core 16 inches long built from standard laminations used in the construction of the largest 3,600-rpm generators, a stationary laminated rotor member to complete the magnetic circuit, and a flexibly connected ring-type

Figure 4. Model of stator core for 3,600-rpm turbine generator

frame member. A two-pole three-phase winding was provided in the stator core and was supported in the slots by slot wedges installed in the conventional manner. The model was mounted with the axis in the vertical direction in order to simplify and reduce the cost of the assembly. The flexible ties between the stator core and the frame allowed relative radial motion of individual parts of the stator core with respect to the frame, but prevented relative lateral motion. Practically no tangential flexibility was provided in the supports. The stator winding had sufficient capacity to produce a rotating magnetic field in the air gap of 60,000 lines per square inch for any single- or three-phase supply frequency up to 130 cycles per second.

Tests were made to determine the effect of frequency, magnitude of air gap magnetizing flux, pressure between laminations, and the flexibility of supports on the vibration of the stator core and frame housing. The test results showed that the curve of stator-core vibration as a function of frequency had a sharp resonance peak with the natural frequency at 222 cycles per second. Actual vibration measurements at different points on the stator core checked closely with the values obtained by analysis. The reduction in pressure between laminations obtained by relieving the tension on the through bolts had no effect on the vibration performance of the core, although it is believed that this was due to the fact that the punchings were tightly cemented together with varnish and did not loosen when the bolt pressure was relieved.

The vibration data obtained by test and analysis indicates that the radial motion of any point at the back of the stator core is approximately 0.001 inch and the tangential motion is essentially zero. This simplifies the support problem since flexibility is required in only the radial direction. The general type of problem is basically the same as that satisfactorily applied to slower-speed single-phase 25-cycle generators except that in the single-phase generator, the output torque is pulsating at double frequency and tangential flexibility must be provided for the stator-core supports, whereas in this case radial flexibility only must be provided. Test results on the model showed that the use of the flexible stator-core supports decreased the magnitude of the double frequency transmitted to the frame to a small percentage of the value obtained with a conventional assembly.

In order to expedite the solution of the mechanical problems and develop the construction details involved in providing stator-core supports with radial flexibility, this principle of design is being first applied on a 12,500-kva 3,600-rpm turbine generator. This generator will be operated under both load and sudden short-circuit conditions to determine the adequacy and effectiveness of the design in accomplishing the desired results from the standpoint of objectionable noise and vibration.

Summary

Double-frequency rotor vibration due to different rigidity constants for the two major axes in two-pole 60-cycle generators can be eliminated by equalizing the rigidity constants on the two axes. This can be accomplished without introducing any reduction in flux capacity by machining narrow transverse slots in the body of the poles.

The double-frequency vibratory forces inherent in two-pole generator stators cannot be eliminated. It is further believed that acceptable results cannot be economically obtained by reducing the air-gap magnetic densities and increasing the rigidity of the stator core over that normally obtained when magnetic conditions are adequately satisfied. Also the stator vibration is not of an amplitude considered to be harmful; consequently, the most practical solution is to isolate the stator core by means of flexible supports, and thus materially reduce the magnitude of the disturbing forces transmitted to the stator frame, foundation supports, and associated apparatus.

Discussion

M. D. Ross (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): This paper covers two very important moves to reduce or eliminate vibrations of rotor and stator parts of two-pole generators, which have been present to a certain degree in all machines of this type. These effects are aggravated in the larger two-pole machines and have reached the point where it was desirable to take some steps to reduce them to levels comparable to those in the smaller two-pole machines.

The stator-frame vibration in some of the large machines which have been built has been responsible for considerable 120-cycle noise; whether it is noticeable in the turbine room depends largely upon the number of machines operating in the same room and upon the size and shape of the room. Noise levels in most turbine rooms at the operating floor level usually run from 95 to 100 decibels. This noise is made up of a large number of frequencies and usually varies markedly from one point to another due to reflections of sound waves from turbine-room walls and floor. Reducing the vibration of the generator frame as outlined in this paper will reduce the generator noise, but may not greatly reduce the noise level reading of the room due to noises from other sources.

It would, therefore, seem logical to consider using sound-proofing material on the walls and ceiling of the turbine room, to absorb the noise and reduce the over-all noise level in the room. The average turbine room with its hard walls and floor has very low sound-absorption properties. When a large total sound energy is released in such a confined space, the noise level is considerably increased due to the reflections from the walls. If, on the other hand, the walls had high absorptive properties, the reflections would be largely eliminated. A striking example of this may be noted in the case of a well-known sound-proofed telephone booth in considerable use in turbine rooms. One side of this booth is open to the room, but the noise level inside is low enough to permit satisfactory telephone conversation while this would be impossible outside the booth.

Where sound-proofing of the engine room has been tried with Diesel engines, we understand the reflected sounds have been practically eliminated. It would seem that this factor should be considered in the design of future turbine rooms. With such moves as described in this paper to reduce noise at its source and a related move to reduce the effect of such noise as remains in the room, a much more satisfactory installation could be obtained.

H. D. Taylor (General Electric Company, Schenectady, N. Y.): The authors' observations regarding double-frequency rotor vibration agree for the most part with tests made by the writer and described in the ASME paper to which they refer. One exception may be mentioned that in our tests the double-frequency rotor vibration did not persist throughout the entire speed range, but was found to be small at the main critical speed, and entirely negligible at running speed.

With regard to the suggestion that internal damping in the rotor bodies of large turbine-generators might be sufficient to overcome the tendency toward instability at the main critical speed, it has always been the writer's understanding that internal or "rotating" damping was an extremely undesirable property for high-speed rotors, in that it tends to promote "whipping" or nonsynchronous vibration at the critical frequency when operating above the critical speed. This tendency is entirely apart from the promotion of similar vibration by the oil film in journal bearings at speeds of about twice critical or higher, although the two may both be present and add their effects.

The running performance of some 15 or 20 large 3,600-rpm generators from 25,000 to 66,667 kva placed in service by the General Electric Company in the past two or three years has failed to disclose any difficulty due to unequal mechanical rigidity of the rotor body. The subcritical has in general been barely discernible; the main critical has always yielded satisfactorily to balancing operations; and at running speed, the double-frequency vibrations have been so small as to be entirely harmless.

Magnetic vibration of the stator core and frame structure, however, appearing when excitation is applied, has been a real problem. All of these machines have exhibited this form of double-frequency vibration in greater or lesser degree. Contrary to the authors' experience, we have found the amount of vibration *on the machines themselves* to be very consistent on machines of similar design. The amount of noise resulting from this vibration has varied widely, depending on at least two sets of conditions: (1) the presence or absence of adjacent structures responsive to 120-cycle stimulation, serving as "sounding boards," and in a number of cases producing a great deal more noise than the generator itself; (2) the acoustic properties of the turbine room, which may promote reflections and reverberations of the radiated sound waves in such a way as to amplify the general noise level.

We have made a study of the design factors affecting the magnitude of this magnetic vibration, and, on the basis of analysis and test data, have concluded that a very definite and desirable reduction can be obtained economically by increasing the rigidity of the core. Reductions of the order of two to one can be had, we believe, with only a small increase in the cost of the generator, of the order of 5 per cent or less. The authors' point as to whether this amount of reduction will be satisfactory is well taken. We have made tests in one customer's plant in which the generator voltage was reduced to a point where the noise became unobjectionable, and the corresponding reduction in vibration amplitude was found to be just two to one. This, we realize, may not hold in all cases. For the past year, however, all our new designs for large 3,600-rpm machines have had the core structure stiffened to reduce magnetic vibration; one of these machines has recently gone through factory tests, and shows a very gratifying improvement, meeting our expectations fully.

As a further step to take care of cases which may need a greater reduction, we have also been developing an elastic mounting of the core structure inside the frame, for the purpose of isolating the remaining vibration at its source. Our analysis and tests have both indicated that, even on a core of great radial depth, the tangential vibration at the outer diameter may not be negligible, and we feel therefore that it is desirable to provide both tangential and radial flexibility in the core supports.

Sterling Beckwith (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): The papers by Snell, Ross and Sterrett, Laffoon and Rose, and Mortensen and Ryan are all closely related, and will all be discussed together.

The use of hydrogen in condensers and frequency changer sets is not new, nor is its use in small experimental turbine generators new. However, the spectacle of at least a dozen large turbine generators all about twice as large as the largest previous machines and all on order and designed for hydrogen by three different companies before a single one was in operation is exceedingly unusual and interesting.

One of the first things noticed about a hydrogen-cooled machine is the additional piping and control necessary above that required for an air-cooled machine. A large part of this apparent complication is due to three factors. The first is the control circuit, but if this circuit is compared with other station control circuits, it will be found to be relatively simple. The second factor is the hydrogen-control piping which is perhaps somewhat complicated in its entirety, but since most of it is used only at very rare intervals when the hydrogen is admitted to or exhausted from the generator, its operation is not a problem. The third factor is the oil-supply and vacuum-treating equipment, but as a second supply is provided so that shutdown of the vacuum-treated supply is permissible, the reliability of the machine as a whole is not greatly affected by the added complications of the oil-supply system.

Some of the complications are perhaps unnecessary, and may be eliminated in the future. The relief valve, for example, is hardly necessary since the duration of any explosion would be too short for it to afford any relief of pressure in the machine, and secondly the complete failure of the hydrogen-supply control valve which may admit a cylinder or more of hydrogen to the machine would not necessarily produce dangerous pressures. Furthermore the alarm system gives an immediate indication of excessive pressures in the machine.

When a hydrogen-cooled machine is in operation, its extreme quietness compared with other 3,600-rpm machines is very apparent. This is due chiefly to the heavy weight of the explosion-proof housing, and the absence of flat panels in its exterior walls, as it would be quiet with air as well as with hydrogen.

In operating at high hydrogen pressures to obtain increased generator output, hydrogen leakage through the housing will vary very nearly in proportion to the square root of the pressure. Consequently a normal leakage of 30 cubic feet a day at four inches of water will become about 300 cubic feet per day at 15 pounds pressure. Such a large leakage may not be justified for continuous operation, but could readily be justified for short time or emergency overloads.

Critical speeds of a two-pole rotor have an additional subharmonic because of the lack of slots near the center of the poles. This is shown in figure 3 of the paper by S. H. Mortensen and J. J. Ryan, and in figure 2 of the paper by C. M. Laffoon and B. A. Rose. That one machine only should cause trouble from this source, as mentioned in the second of these articles, is somewhat unexpected and leads one to wonder how such other possibilities as forging dissymmetry and foundation variations can be eliminated. The writer's experience with several large machines has indicated no difficulty from the unequal moments of inertia.

B. A. Rose: Mr. Taylor is correct in his statement that internal damping in a shaft tends to promote nonsynchronous vibration at the critical frequency when the rotor is operating above the critical frequency. The statement in the paper to which this point refers is a little misleading in that it should have referred to operation at the critical speed only. On the other hand, the Westinghouse company has encountered no trouble with its 3,600-rpm generator rotors from this cause, even though most of them are designed to operate above their critical speeds.

Mr. Taylor further states that the General Electric Company have experienced no trouble with double-frequency rotor vibration on any of their large-capacity 3,600-rpm machines. The writers believe this can be explained by the fact that the machines in question have no rotor critical frequencies near 120 cycles per second. We have found that our ability to calculate the critical frequencies for the mode of vibration in question is not sufficiently accurate to rely on it for this purpose and have found that the elimination of the nonuniform rigidity is a more positive means of avoiding the trouble.

We are pleased to observe from Mr. Taylor's discussion of the stator vibration problem that, in general, his experiences and theories concerning the phenomenon agree with ours. Their method of providing a flexible core support when announced probably will differ in its detail construction from the one described but will accomplish the required isolation of the core from the frame structure and foundation.

The Hydrogen-Cooled Turbine Generator

D. S. SNELL
ASSOCIATE AIEE

HYDROGEN cooling for electrical machinery was first proposed to the industry through an AIEE paper presented in 1925.[1] The first hydrogen-cooled machine to be placed in commercial service was a 12,500-kva synchronous condenser, installed in 1928.[2] This was followed by other machines of this type, and later, the hydrogen-cooled frequency-converter was introduced. There are now in operation in the United States 20 of these two types of hydrogen-cooled machines, with a combined output of over one-half million kva, and their records of performance have been highly satisfactory. Prior to 1937, the application of hydrogen cooling to turbine generators had been confined to developmental machines in the manufacturers' plants, although several air-cooled generators had been built with provision for later adaptation to hydrogen cooling. In October 1937 the first hydrogen-cooled generator built for commercial service was placed in operation at Dayton, Ohio. This was a 3,600-rpm unit, of General Electric manufacture, rated at 31,250 kva at 0.8 power factor. Since then, a total of 10 hydrogen-cooled generators have been placed in service in various parts of the country, and 27 others are in the course of installation or construction. The total capacity of these 37 generators is over 2,000,000 kva, and their sizes range from 17,000 kva to 81,250 kva at 3,600 rpm, and from 75,000 kva to 176,470 kva at 1,800 rpm.

Two papers have already been presented before the Institute, in which the development and design work of one large manufacturing company in connection with the hydrogen-cooled generator have been described.[3,4] It is the purpose of the present paper to describe the work of another large company in the commercial development of this new-type machine, and to present some of the results of several months' operating experience with eight of these machines.

Advantages of Hydrogen as a Cooling Agent

These have been stated many times before, and are here mentioned only in the interest of completeness.

1. Windage and ventilation losses in hydrogen are only about one-tenth of their value in air, due to the lower density of hydrogen.
2. The rating of a machine can be increased approximately 20 per cent for a given amount of active material, by operation in hydrogen instead of in air, due to the superior cooling properties of hydrogen.
3. The life of the winding insulation is increased, due to the absence of moisture, oxygen, and dirt, and to the fact that corona damage is eliminated, in the hydrogen-cooled machine.
4. The fire hazard is eliminated.

The reduction of the windage and ventilation losses of a turbine generator with hydrogen cooling increases the full-load efficiency about 0.7 per cent for 1,800-rpm machines and about 0.9 per cent for 3,600-rpm machines. In figure 1 are shown the estimated net yearly savings with hydrogen cooling for different sizes of generators, corresponding to these increases in efficiency. These savings assume a power cost of 0.3 cent per kilowatt-hour and an operating time of 80 per cent and take account of the cost of the hydrogen and carbon dioxide required for operating and filling. They also assume the installed cost of the hydrogen-cooled generator to be the same as that of the air-cooled generator, which is usually the case. The savings thus calculated are shown to range from about $4,000 a year for a 25,000-kw 3,600-rpm unit to about $20,000 a year for a 160,000-kw 1,800-rpm unit.

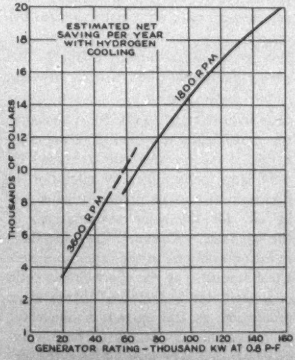

Figure 1. Estimated net yearly saving by using hydrogen in place of air as the cooling agent, for generators in different sizes

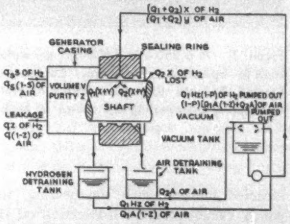

Figure 2. Schematic diagram of shaft-sealing system for hydrogen-cooled generators, using vacuum-treated oil

The greater output per pound of material obtained with hydrogen cooling, extends the limit of output of generators of the 3,600-rpm type and allows the building of generators with self-ventilation in capacities which, if built for air cooling, would require external fans. The largest capacity at 3,600 rpm now considered practicable with air cooling is about 62,500 kva, and such a machine would have external fans; with hydrogen cooling, generators as large as 81,250 kva at 3,600 rpm are practicable, ventilated with internal fans.

Type of Shaft Seal Used

The most important part in the development of the hydrogen-cooled generator was the design of a means for sealing the rotating-shaft extensions against the outward leakage of hydrogen. After investigating many different sealing arrangements, of the mechanical, combination mechanical-and-liquid, and liquid-film types, the General Electric Company finally adopted the liquid-film type of seal for use with its hydrogen-cooled generators. This type of seal is illustrated schematically in figure 2 and includes a sealing ring surrounding the shaft, con-

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The development of the hydrogen-cooled generator described in the foregoing was carried out under the direction of M. A. Savage, and in collaboration with Chester W. Rice, E. H. Freiburghouse, and Robert Hannah. The electrical system of the hydrogen control cabinet was designed by E. J. Flynn and A. J. Bialous. The tests on the Logan and Cincinnati generators were obtained through the co-operation of the Appalachian Electric Power Company and the Cincinnati Gas and Electric Company, which co-operation is hereby gratefully acknowledged.

1. For all numbered references, see list at end of paper.

Figure 3. A 6,250-kva 3,600-rpm generator built for operation in hydrogen. Coolers are located beneath the rotor. Vacuum tank for treating shaft-sealing oil shown in background

structed integral with the bearing, to which vacuum-treated lubricating oil is supplied under pressure.[5,8] This creates a film of oil completely surrounding the shaft which prevents the escape of hydrogen from the casing at this point. This type of shaft seal has the advantages of simplicity and ruggedness, and through operating with vacuum-treated oil both permits a high degree of hydrogen purity to be maintained in the generator casing and prevents the contamination of the oil in the bearing lubrication system by the hydrogen.

Tests on a 6,250-Kva Hydrogen-Cooled Generator

In 1926 a 6,250 kva, 3,600-rpm hydrogen-cooled generator was built by the General Electric Company for developmental purposes. This machine, figure 3, was provided with a heavy, cylindrical casing, cast-steel end shields, and with two gas coolers, contained in a rectangular box beneath the rotor. A shaft seal of the oil-film type was provided in each generator bearing. This machine was tested as a synchronous condenser in hydrogen and in air over a period of about 12 months, during which time the operating characteristics of the seals and auxiliary equipment could be observed and information on the heating of the machine in hydrogen and in air obtained. The more important of the heating data obtained in the tests are summarized in figures 4 to 6.

Figures 4 and 5 give the field and armature heating characteristics of the 6,250-kva generator for different loss intensities on the coil surfaces, with air, carbon dioxide, and hydrogen as the cooling media, the tests in hydrogen having been conducted at three different hydrogen pressures. Curves for cooling with helium have been added, based on calculation. The armature heating curves in figure 5 have had deducted the calculated temperature rise of the gas in the air gap due to field I^2R loss. This rise is of the order of from three to five degrees centigrade. This was done in order to use the curves for estimating the armature temperature rise at 0.8 power factor loads, the tests having been made at zero power factor.

The temperature difference between armature copper and between-coil temperature detector for different armature loadings, in air and in hydrogen, is shown in figure 6. At normal load, corresponding to a loss intensity of about 0.3 watt per square inch, this temperature difference is about 15 degrees centigrade in air as compared with 11.4 degrees centigrade in hydrogen at 0.44 pound per square inch pressure. The lower values of the temperature difference at higher hydrogen pressures indicate a slight increase in the thermal conductivity of the insulation at the higher pressures. The crossing of the curves at the higher armature loadings may be due to changes in the insulation occurring at the higher temperatures.

From the foregoing tests, and tests made on stationary models, it was determined that the thermal conductivity of the armature insulation was increased about ten per cent by operation in hydrogen instead of air, while that of the field insulation was practically doubled. These increases in thermal conductivity are practically independent of the hydrogen pressure. The forced heat convection from the internal machine surfaces was estimated to be increased between 30 and 50 per cent by operation in hydrogen at 0.44 pound per square inch pressure instead of in air. For increased hydrogen pressures the forced heat convection varies approximately with the 0.8 power of the absolute hydrogen pressure.

The heating data obtained in these tests indicate that the 6,250-kva generator as originally designed could have its rating at 0.8 power factor increased by very large percentages by operation in hydrogen at various pressures instead of in air, for the same temperatures of the windings. However, these increases in rating would be at the expense of electrical stability, as the short-circuit ratio of a generator is decreased in the same proportion as the output is increased. To obtain the same stability from the hydrogen-cooled generator as from the air-cooled one, the former must be proportioned somewhat differently. For the 6,250-kva generator redesigned for the same short-circuit ratio at all ratings (by maintaining the same stator core dimensions but varying the rotor diameter) the increases in output with hydrogen cooling over the normal air rating, for the same winding temperatures, would be approximately 20, 30, and 35 per cent for hydro-

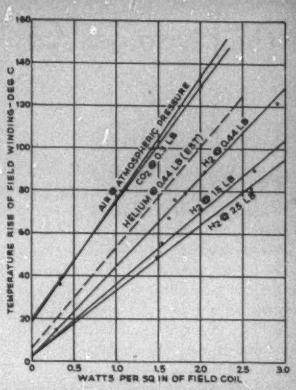

TEMPERATURE RISE OF FIELD WINDING—DEG C
WATTS PER SQ IN OF FIELD COIL
AIR @ ATMOSPHERIC PRESSURE
CO2 @ 0.3 LB
HELIUM @ 0.44 LB (EST)
H2 @ 0.44 LB
H2 @ 15 LB
H2 @ 25 LB

Figure 4. Field heating characteristics of a 6,250-kva generator with respect to temperature of gas leaving coolers, from tests with generator operating in different cooling gases

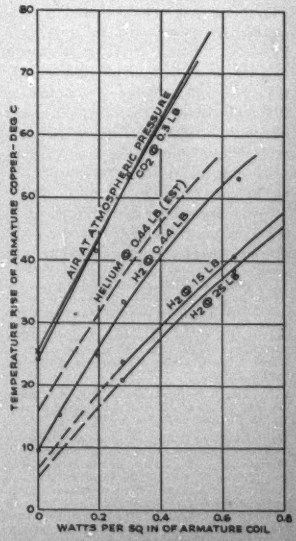

TEMPERATURE RISE OF ARMATURE COPPER—DEG C
WATTS PER SQ IN OF ARMATURE COIL
AIR AT ATMOSPHERIC PRESSURE
CO2 @ 0.3 LB
HELIUM @ 0.44 LB (EST)
H2 @ 0.44 LB
H2 @ 15 LB
H2 @ 25 LB

Figure 5. Armature heating characteristics of a 6,250-kva generator with respect to temperature of gas leaving coolers, from tests with generator operating in different cooling gases

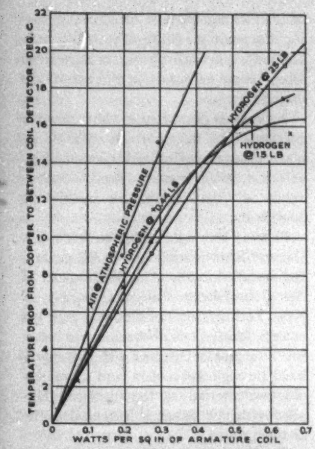

TEMPERATURE DROP FROM COPPER TO BETWEEN COIL DETECTOR - DEG. C
WATTS PER SQ IN OF ARMATURE COIL
AIR @ ATMOSPHERIC PRESSURE
HYDROGEN @ 0.44 LB
HYDROGEN @ 15 LB
HYDROGEN @ 25 LB

Figure 6. Temperature drop from armature copper to between-coil temperature detector, for different watts per square inch of armature coil, from tests on a 6,250-kva generator operating in air and in hydrogen

gen pressures of 0.44, 15, and 25 pounds per square inch, respectively.

Other Cooling Gases

Tests on the 6,250-kva generator using carbon dioxide as the cooling agent indicated, as shown in figures 4 and 5, that the heating of a machine in this gas is practically the same as with air cooling. Although the density of carbon dioxide is about 50 per cent greater than that of air and its thermal conductivity is about 35 per cent less, these disadvantages are compensated for, with respect to the heating of the windings, by the fact that the forced heat-convection coefficient is about 20 per cent greater in carbon dioxide than in air, and the product of specific heat and density is 39 per cent greater for carbon dioxide than for air, so that 39 per cent more heat can be absorbed by a given volume of the gas for the same temperature rise. Although there is no advantage in the use of carbon dioxide as the cooling agent for generators, as its higher density greatly increases the windage losses, there appears to be a distinct field for its use in the case of induction motors intended for operation in explosive atmospheres. In the past year the General Electric Company has placed in service two induction motors of this type, using carbon dioxide as the cooling agent, the motors being provided with shaft seals similar to those used with hydrogen-cooled generators.

The use of helium as the cooling gas for rotating machinery has been frequently proposed, and has the advantage of effecting a reduction in windage and ventilation losses comparable with that obtained with hydrogen, without the attendant disadvantage of inflammability in mixture with air, possessed by hydrogen. However, as shown by the curves in figures 4 and 5, the cooling effect with helium is distinctly inferior to that obtained with hydrogen, so that the increase in output of a generator by using helium in place of air as the cooling agent would be considerably less than that obtained by the use of hydrogen in place of air.

Generator Construction

The type of construction employed with most of the hydrogen-cooled generators built by the General Electric Company is illustrated in figure 7 and includes a cylindrical, gas-tight, outer casing, reinforced with a number of annular supporting-plates. Four gas coolers are usually provided, located within the casing with their long axes parallel to the horizontal axis of the machine. The cooler tubes are made accessible for cleaning without removing the hydrogen from the casing by removing cover plates at either end of the frame. In another design two coolers are used, placed lengthwise of the generator and located in either the top half or the bottom half of the casing.

The outer end-shields of the generator are of either cast-steel or fabricated construction and are usually employed to support the generator bearings, thus minimizing the distance between bearing centers. The joint surfaces between the end-shield halves and between the shields and the casing are carefully machined, and are provided with grooves within the bolting line into which a plastic compound is forced, thereby minimizing the possibility of hydrogen leakage from the joints

The frame construction is designed to withstand safely the explosion pressure of the most explosive mixture of hydrogen and air, with the generator operating at a

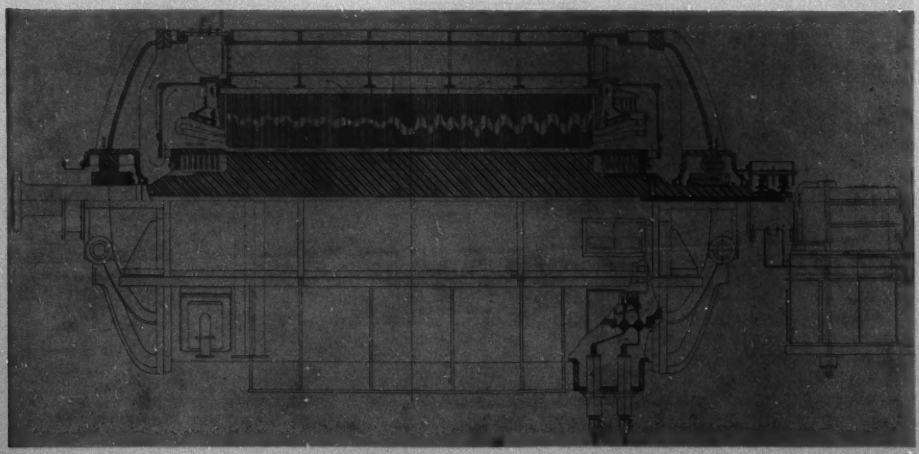


Figure 7. Longitudinal cross-section view of a 55,555-kva 3,600-rpm hydrogen-cooled generator

Figure 8. A 53,000-kw 3,600-rpm steam turbine-generator set, generator hydrogen cooled

hydrogen pressure of 15 pounds per square inch. This explosion pressure is estimated to be approximately 100 pounds per square inch.

The rotors of 3,600-rpm hydrogen-cooled generators consist of solid, one-piece steel forgings, having slots milled out of the body portion for carrying the field winding. For many of these generators the field winding is made from aluminum, instead of from copper, which, due to the lower specific weight of aluminum, permits a larger rotor diameter to be employed than with the copper winding and thereby secures a greater rigidity for the rotating shaft. The low rotational loss in hydrogen permits such an increase in rotor diameter, which would not be practical with air cooling.

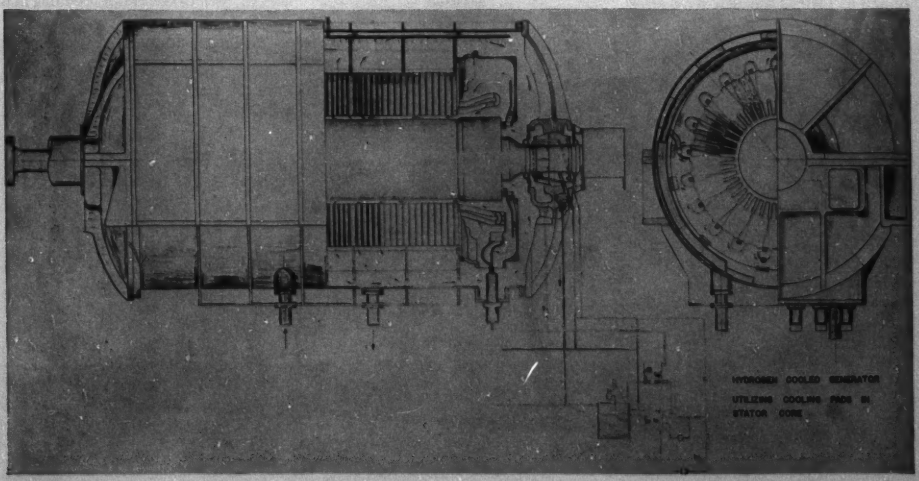
The ventilation of these generators, in all sizes but the very largest, is provided by two centrifugal fans, mounted one on either end of the rotor. For the 176,470-kva 1,800-rpm hydrogen-cooled generator of the Chicago District Electric Generating Corporation, State Line, Ind., ventilation is provided by four motor-driven fans, housed in domes in the top of the casing.

A device is connected to the bottom of the generator casing which operates an alarm if water or oil should start to collect, as could result from a defective cooler-tube or from improperly-functioning shaft seals.

Figure 8 shows a 58,889-kva 3,600-rpm General Electric hydrogen-cooled generator, installed in the Waterside station of the Consolidated Edison Company of New York. This machine has four gas coolers, located two above and two below the floor line. Distilled water is circulated through the coolers, and a heat exchanger external to the machine, supplied with raw water, is used to cool the distilled water.

The 50,000-kva 3,600-rpm hydrogen-cooled generator of the Appalachian Power Company at Logan, W. Va., employs a novel cooling system in which the stator core is cooled by direct contact of the laminations with a number of hollow metal pads, located between the lamination packages, through which distilled water is circulated.[8] The construction of this machine is illustrated in figure 9. The rotor, and the armature end-windings are cooled by the circulation of hy-

Figure 9. Longitudinal and end cross-section views of a 50,000-kva 3,600-rpm hydrogen-cooled generator having water-filled cooling pads in the stator core



drogen over them, the heated hydrogen being cooled at the center of the machine in passing to the back of the core through ducts formed between special finned pads and the laminations. A heat exchanger external to the generator is used to cool the distilled water circulated through the pads. While no other generators of the pad-cooled type have since been built, this cooling arrangement is believed to have several advantages which may sometime encourage its more general use. The use of cooling pads in place of the customary gas coolers permits a more compact construction and reduces the volume of gas that needs to be circulated.

Operating Hydrogen Pressure

The hydrogen-cooled generators built by the General Electric Company are designed to operate normally at a hydrogen pressure of approximately one-half pound per square inch. Several machines have been built, however, with provision for operating at hydrogen pressures up to 15 pounds per square inch, if such operation should become desirable for securing additional kilovolt-ampere output or lower generator temperatures under abnormal water-temperature conditions. Operation at hydrogen pressures greater than about 1.5 pounds per square inch requires the provision of additional control features in the seal-oil and gas control systems.

Shaft Sealing System—Characteristics

Seals Supplied with Vacuum-Treated Oil

The equations for the shaft sealing system employed with these generators are derived in the appendix. These show that, with vacuum-treated oil supplied to the shaft seals, the degree of hydrogen purity maintained in the generator casing is a function chiefly of the degree of vacuum treatment of the oil and the amount of leakage from the casing. The purity is shown to change exponentially with time, following the initial starting-up of the generator, finally reaching a constant value. The amount of hydrogen continuously required by the generator is shown to equal approximately the casing leakage plus the amount of hydrogen absorbed by the sealing oil.

Figure 10 shows the calculated variation in hydrogen purity with time following the starting-up of the generator, for different degrees of vacuum treatment of the sealing oil, for the 50,000-kva 3,600-rpm Logan generator. A leakage from the casing of 0.27 cubic foot per hour has been assumed, based upon tests. The curves show that several weeks of operation are required for the hydrogen purity in the casing to reach the final value corresponding to the vacuum and leakage also that the final value is independent of the initial hydrogen purity in the casing.

Figure 11 shows the calculated final hydrogen purity in the generator casing for different degrees of vacuum treatment of the sealing oil and different assumed values of the casing leakage, for the Logan generator. A curve showing the estimated yearly cost of the windage and ventilation losses of this machine for different values of hydrogen purity in the casing is also given, which illustrates the economic advantage of operating at a high purity. This curve was calculated for an assumed power cost of 0.3 cent per kilowatt-hour and an operating time of 80 per cent. It can be shown from the curves of figure 11 that for values of vacuum treatment less than about 29 inches, a slight casing leakage may increase the hydrogen purity sufficiently to effect a saving in cost of windage loss comparable with the cost of the hydrogen wasted. In practice, however, it is preferable to maintain a high hydrogen purity by maintaining a high degree of vacuum treatment, rather than by leakage, and to have the casing leakage as small as possible.

A high hydrogen purity is, of course, essential from the standpoint of safety, as well as of economy, of operation, since a mixture of less than 72 per cent hydrogen in air is explosive. In practice it is usual never to allow the hydrogen purity in the generator casing to decrease below 90 per cent.

The degree of vacuum treatment of the sealing oil is determined by the effectiveness of the treating system. For the spray-recirculation system of vacuum treatment used with these generators, the vacuum treatment obtained is generally between 0.1 and 0.3 inch less than the vacuum held in the vacuum tank.

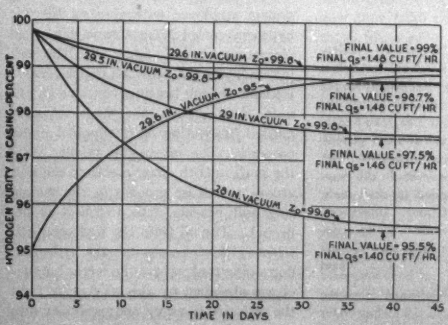


Figure 10. Calculated per cent hydrogen purity in casing of a hydrogen-cooled generator versus time for different degrees of vacuum-treatment of oil supplied to shaft seals

Barometer 30 inches. Final hydrogen purity by test 99 per cent for 29.7 inches vacuum in vacuum tank. Hydrogen consumption by test 1.48 cubic feet per hour. Hydrogen pressure in casing 10 inches water

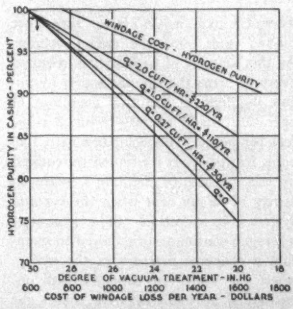

HYDROGEN PURITY IN CASING - PERCENT
WINDAGE COST - HYDROGEN PURITY
Q=2.0 CU FT/HR. $320/YR
Q=1.0 CU FT/HR. $160/YR
Q=0.27 CU FT/HR. $ 50/YR
Q=0
DEGREE OF VACUUM TREATMENT - IN. HG
COST OF WINDAGE LOSS PER YEAR - DOLLARS

Figure 11. Calculated per cent final hydrogen purity in casing of a hydrogen-cooled generator for different degrees of vacuum-treatment of oil supplied to shaft seals and different rates of hydrogen leakage q. Also estimated yearly cost of windage losses versus per cent hydrogen purity

Hydrogen pressure ten inches water

Seals Supplied with Untreated Oil

If the shaft seals are supplied with untreated oil, as may occur under certain emergency conditions of operation, the air given up from the oil flowing to the hydrogen side of the seals will cause the hydrogen purity in the casing gradually to decrease. This will require that the casing be scavenged at intervals with fresh hydrogen to keep the purity always above 90 per cent. Figure 12 shows the calculated and test values of hydrogen purity under this condition of operation, for the Logan 50,000-kva generator.

The curves show that, for the normal rate of oil flow to the seals, with untreated oil, it is necessary to scavenge the generator casing with fresh hydrogen about once every 15 hours, to maintain the purity between 90 and 95 per cent. The amount of hydrogen of 99.8 per cent purity required to increase the hydrogen purity in the casing from 90 to 95 per cent is, approximately,[7]

$$0.7 \times 2.3 \times 1{,}000 \log \frac{99.8-90}{99.8-95} = 500 \text{ cubic feet}$$

where the coefficient 0.7 is an "experience factor" and 1,000 the casing volume. As this amount of hydrogen is required every 15 hours the average hourly hydrogen requirement for this condition of operation would be $500/15 = 33.3$ cubic feet per hour. This compares with 1.48 cubic feet per hour continuously required by this machine to maintain a hydrogen purity of 99 per cent when the vacuum system is in operation. (The amount of hydrogen continuously required to maintain a constant pressure in the casing, when the seals are supplied with untreated oil, is usually negative, that is, gas must be vented from the casing. This follows from the fact that for small values of casing leakage more air is brought into the casing by the sealing oil than hydrogen is discharged by absorption and leakage.)

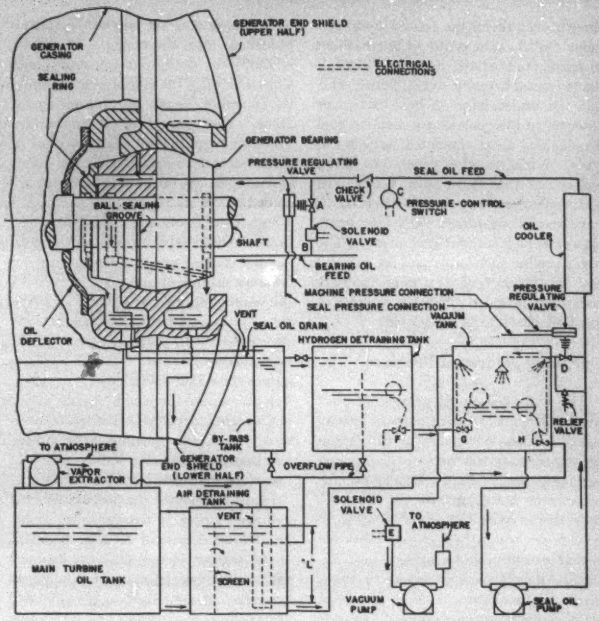


Figure 13. Arrangement of shaft-sealing system for hydrogen-cooled generator, with detail of shaft-sealing arrangement shown for one generator bearing. Arrangement for other bearing is similar

Standstill Operation of Seals

The characteristics of the shaft-sealing system with the generator at rest are somewhat different than with the generator operative, owing to the different values for the gas solubilities in the oil to be used in the seal equations. With vacuum-treated oil supplied to the seals, two different values for both the hydrogen and the air solubilities must be used; for the absorption of gas by the vacuum-treated oil, about the same solubilities may be assumed whether the shaft is rotating or stationary, while for the release of gas by the oil the gas solubilities should be taken as about one-tenth their values for the rotating condition. With untreated oil supplied to the seals, the gas solubilities used in the seal equations should be taken as about one-tenth their values for the rotating condition. The practical results of these differences in seal characteristics for the stationary and rotating conditions are, that with vacuum-treated oil supplied to the seals the hydrogen requirement is only slightly less with the shaft at rest than with the shaft rotating, but the hydrogen purity in the casing is slightly higher. With untreated oil supplied to the seals, however, the amount of hydrogen required with the shaft at rest is about equal to the casing leakage, and the hydrogen purity decreases only about one-tenth as rapidly as with the shaft rotating.

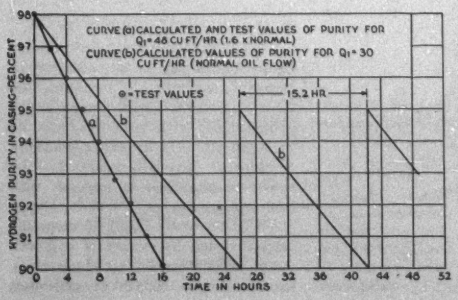


Figure 12. Calculated and test values of per cent hydrogen purity in casing versus time, for a hydrogen-cooled generator operating with untreated oil supplied to shaft seals. Casing scavenged when purity decreases to 90 per cent

Hydrogen pressure 18 inches water

Shaft Sealing System—Arrangement Details

Vacuum-Treating System

The arrangement of the shaft-sealing system employed with General Electric hydrogen-cooled generators is illustrated diagrammatically in figure 13. The sealing ring, which is attached to the generator side of each bearing, contains an annular feed groove to which vacuum-treated lubricating oil is supplied under pressure. The oil passes axially along the shaft in both directions from the feed groove to release grooves in the sealing ring and bearing, into which it is deflected. The oil from the hydrogen-side release grooves passes into the hydrogen-detraining tank, where the larger bubbles of gas absorbed by the oil flowing from the seals are given up and pass back into

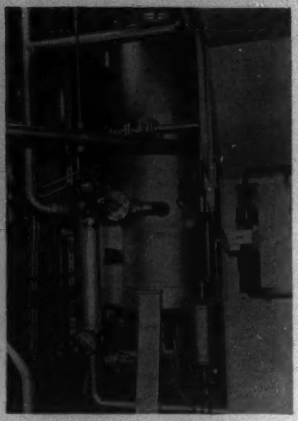


Figure 14. Combination vacuum and hydrogen-detraining tank with auxiliary equipment, for shaft-sealing system of a hydrogen-cooled generator

the generator. The oil from the air-side release grooves unites with the bearing oil and passes to the main oil tank, whence an equal amount flows by gravity to the air-detraining tank (or to an air-detraining compartment in the main oil tank) where the larger bubbles of air contained in the oil are given up. From the hydrogen-detraining and air-detraining tanks the oil passes into the vacuum tank, where practically all of the hydrogen and air remaining in the oil is removed.

Oil is pumped to the seals from the vacuum tank by a rotary pump of the constant-displacement type, having a capacity several times the normal seal oil flow. Pressure regulating valve *D* holds a constant differential between the seal and hydrogen pressures by diverting into the vacuum tank the part of the pump delivery not sent to the seals. The oil diverted through valve *D* enters the vacuum tank through spray nozzles, which serve to expose large areas of the oil to vacuum treatment.

A vacuum of between 0.1 and 0.5 inch of mercury, absolute, is held in the vacuum tank by the operation of a rotary vacuum pump. As the vacuum pump discharges to atmosphere an explosive mixture of hydrogen and air, the pump is made explosion proof.

The by-pass tank shown in figure 13 is used to divert the oil from the seal drain to the air-detraining tank if it becomes necessary to remove the hydrogen-detraining tank from service. Its cross-section area is sufficient to permit partial detraining of the hydrogen from the oil under this emergency condition of operation.

The principal elements of the vacuum-treating system are usually constructed as a unit, as shown in figure 14, and the whole arrangement is conveniently located underneath the generator.

Emergency Seal Oil Supply

In the event of any failure in the vacuum-treating system which would cause failure of the discharge pressure of the seal oil pump, the shaft seals would be supplied with untreated oil from the bearing supply system through pressure-regulating valve *A*, figure 13. This valve is normally open but is prevented from supplying oil to the seals by the normally-closed solenoid-valve *B*. Failure of the discharge pressure of the seal oil pump opens the pressure switch *C*, allowing valve *B* to open. This operation also closes the normally-open solenoid-valve *E* in the suction line of the vacuum pump, preventing the rising of foam in the vacuum tank, which would occur with the spray nozzles unsupplied with oil.

With the shaft seals supplied with oil from the bearing supply system, hydrogen-saturated oil from the seals passes to the air-detraining tank, and thence to the main oil tank, through the overflow pipe in the hydrogen-detraining tank. Operation of the vapor extractor is relied upon to maintain the atmosphere above the oil in the main oil tank well below the lower limit of hydrogen-air inflammability (four per cent) under this condition of operation.

Atmospheric Relief and Scavenging Valves

The maximum operating hydrogen pressure for generators not designed for operation up to 15 pounds per square inch pressure, is represented in figure 13 by the elevation of the oil level in the main oil tank above the low point of the overflow pipe from the hydrogen-detraining tank (dimension *L*). An atmospheric relief valve of the mercury-column type is provided at the hydrogen-detraining tank, figure 15, which discharges hydrogen to atmosphere if the pressure in the casing approaches this limiting pressure. If this valve should fail to operate, hydrogen would be discharged into the vent pipe in the air-detraining tank and would be carried to atmosphere by the vapor extractor.

A solenoid-operated scavenging valve is also provided at the hydrogen-detraining tank, figure 15, operated from the hydrogen control cabinet, which allows hydrogen to be discharged to atmosphere if it becomes necessary to increase the purity of the hydrogen in the casing.

Hydrogen Control

Control System

The system of hydrogen control employed with these generators is illustrated in figure 15. The hydrogen supply is contained in several commercial cylinders, or "bottles," connected with a manifold through pressure-reducing regulators. A solenoid-operated valve controlled by a pressure switch admits hydrogen to the casing from the connected cylinders to maintain the casing pressure within predetermined limits. These are normally from 8 to 12 inches of water.

In filling the casing with hydrogen initially, or in removing the hydrogen from the casing, carbon dioxide is first admitted, through a pipe at the bottom of the casing, and the air or hydrogen discharged from the hydrogen feed pipe. To determine when sufficient carbon dioxide has been admitted to render the mixture nonexplosive with hydrogen or

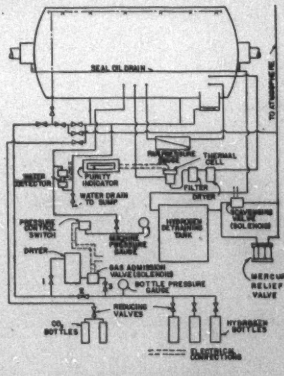


Figure 15. Arrangement of hydrogen piping for hydrogen-cooled generator

air, an Orsat is used, or, in some cases, a special scale on the hydrogen purity indicator is provided.

Purity Indicators

An indication of the percentage hydrogen purity in the generator casing is provided by an instrument operating on the thermal-conductivity principle. Hydrogen from the casing is passed continuously through the analysis cell of the purity-indicating instrument by the action of the generator fans or by continu-

Table I. Heating Tests on 31,250-Kva 3,600-RPM Turbine Generator for Dayton Power and Light Company Operating as a Synchronous Condenser at Zero Power Factor Overexcited

All Temperatures In Degrees Centigrade

	Cooling Medium	
	Air	Hydrogen
Kilovolt-amperes at zero power factor	19,200	30,000
Field input, kilowatts	62.5	98
Temperature of gas to coolers	63.4	46.1
Temperature of gas from coolers	40.3	33.1
Temperature rise of gas through coolers	23.1	13.0
Temperature of water to coolers	15.6	15.3
Temperature of water from coolers	26.5	26.5
Temperature rise of water in coolers	10.9	8.2
Water flow to coolers, relative	1.41	1.0
Temperature rise field winding above ingoing gas	67	67
Temperature rise field winding above ingoing water	91.7	81.8
Temperature rise maximum armature temperature coil above ingoing gas	38	32
Temperature rise maximum armature temperature coil above ingoing water	62.7	46.8

Figure 16. Instrument panel of hydrogen-control cabinet for a hydrogen-cooled generator

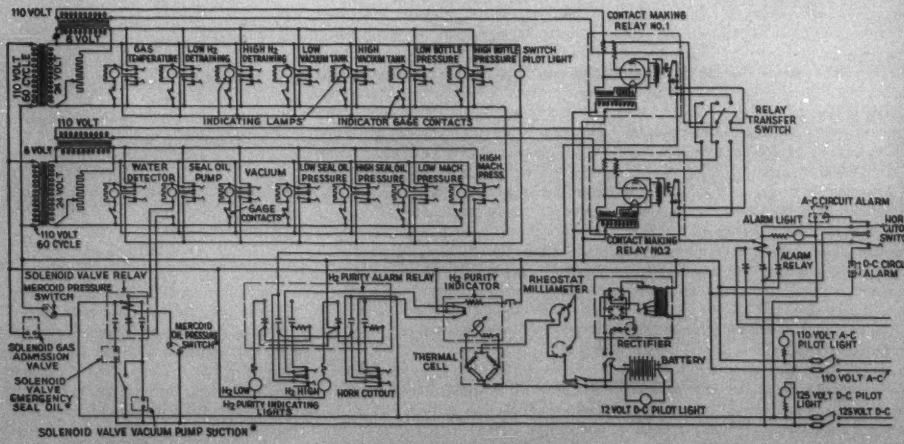
ally wasting a small amount of hydrogen. In the analysis cell a platinum coil, arranged in one of the arms of a Wheatstone Bridge circuit, is passed over by the hydrogen at a slow rate. This coil carries a heating current, supplied by a 12-volt battery, which causes the coil to increase in temperature, and therefore in resistance, by an amount depending upon the thermal conductivity of the gas surrounding it. Since the thermal conductivity of hydrogen is about seven times that of air, a small percentage of air in the hydrogen will cause a relatively large change in the thermal conductivity of the hydrogen and will thus effect a proportionately large change in the coil resistance. The purity indicator is a galvanometer-type of instrument, and indicates the purity of the gas in the analysis cell by comparing the resistance of the above coil with that of a standard coil arranged in another arm of the Wheatstone bridge circuit. A contact in the indicator case operates an alarm to indicate low hydrogen purity.

A secondary indication of the hydrogen purity in the generator casing is provided by the reading of a gauge showing the pressure developed by the generator fans. As the fan pressure, with the generator operating at constant speed, is proportional to the hydrogen density, the scale of this gauge can be calibrated to indicate percentage hydrogen purity.

Control Cabinet

The gas admission device, purity indicating equipment, and the other indicating instruments required for operating the generator in hydrogen are housed in a control cabinet, usually located near the generator on the operating floor. Figure 16 shows the instrument panel of the control cabinet for a 55,555-kva 3,600-rpm hydrogen-cooled generator. The large round instrument shown at the center of the upper row of gauges is the fan-pressure gauge. Directly below it is the hydrogen purity indicator. Other instru-

Figure 17. Schematic diagram of electrical circuits of the control cabinet for a hydrogen-cooled generator. Items with (*) are located away from cabinet



ments shown are the gauge for indicating the hydrogen presssure in the generator casing, the gauge for reading the reduced hydrogen-bottle pressure, a gauge for reading the vacuum in the vacuum tank, and a dial thermometer for indicating the hydrogen temperature at discharge from the coolers. The different instruments are provided with contacts which operate the alarm system of the cabinet to indicate any abnormal condition. The cabinet is mounted on rubber supports to protect the instruments against vibration.

The three hand-valves shown at the bottom of the cabinet in figure 16 correspond with valves 1, 2, and 3 in figure 15.

The alarm system for the control cabinet is represented in figure 17 and includes two contact-making relays of the vacuum-tube type which are used to operate two alarm horns. Operation of the alarm contact of any instrument lights a signal lamp and causes a current to flow through a small step-up transformer; this impresses a grid-bias on the vacuum tube of one of the contact-making relays, causing the relay to drop out and operate the horns. This arrangement permits a minimum passage of current through the instrument contacts for the operation of the horns.

Operating Experience with Eight Hydrogen-Cooled Generators

Within the past 18 months eight General Electric hydrogen-cooled generators in capacities ranging from 31,250 kva at 3,600 rpm to 176,470 kva at 1,800 rpm and with a combined output of 522,164 kva, have been placed in service. The individual ratings of these machines, and their service records, are given in figure 18. These units have operated almost continuously since installation, with no outages from faulty operation of the hydrogen features, and have amply demonstrated the many advantages of hydrogen cooling. The rates of hydrogen consumption have averaged from 35 to 60 cubic feet per day for the six 3,600-rpm units, and are about 65 and 120 cubic feet per day respectively for the two 1,800-rpm units. The costs of these amounts of hydrogen range from $0.45 to $1.50 per day. The hydrogen purities in the casings of these machines have been maintained at values between 97.5 and 99 per cent.

Although some little time is usually required to familiarize the operators with the various details of the auxiliary equipment no real operating difficulties have been encountered, and in most cases the operators have come to regard the operation of hydrogen-cooled generators as being only little more complicated than the operation of the air-cooled type of machine.

Heating Tests on a 31,250-Kva Generator

The first hydrogen-cooled generator to be placed in commercial service, the 31,250-kva 3,600-rpm Dayton machine, was given extensive tests in hydrogen and in air previous to shipment. Some of the test results are shown in table I and figure 19. It will be observed from table I that this machine, operating at zero power factor, carried in hydrogen approximately

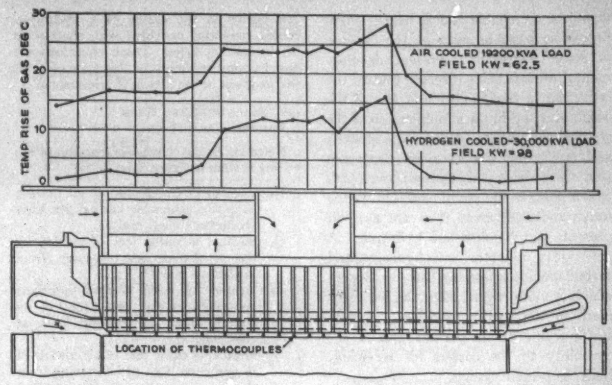


Figure 19. Temperature rise of cooling gas in ventilation circuit of a 31,250-kva 3,600-rpm generator built for operation in hydrogen, from tests in air and in hydrogen, with generator operating as an overexcited synchronous-condenser at zero power factor

Paths of ventilating gas shown by arrows

56 per cent greater load than in air for the same temperature rise of the field winding, with respect to the temperature of the gas leaving the coolers, while the armature winding operated at a temperature rise even lower. Operating with air as the cooling medium, this generator could carry nearly full load rating with the same heating of the windings as for a standard air-cooled machine. In hydrogen the full-load temperature rises are considerably lower than the normal values for air-cooled machines. The curves of figure 19 show the marked reduction with hydrogen cooling, in the temperature rise of the gas in the air gap —which has an important influence on the heating of the rotor—due to the lower rotational loss in hydrogen.

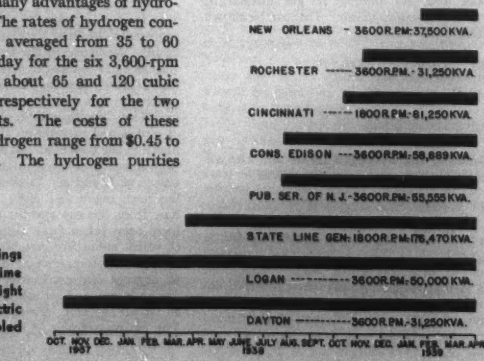

NEW ORLEANS - 3600 R.P.M. 37,500 KVA.
ROCHESTER - 3600 R.P.M. - 31,250 KVA.
CINCINNATI - 1800 R.P.M. 81,250 KVA.
CONS. EDISON - 3600 R.P.M. 58,889 KVA.
PUB. SER. OF N. J. - 3600 R.P.M. 55,555 KVA.
STATE LINE GEN. 1800 R.P.M. 176,470 KVA.
LOGAN - 3600 R.P.M. 50,000 KVA.
DAYTON - 3600 R.P.M. - 31,250 KVA.
OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR.
1937
1938
1939
1940

Figure 18. Ratings and lengths of time in service of eight General Electric hydrogen - cooled generators

Future Trends in Generator Design

It will be apparent, from the large number of hydrogen-cooled generators now in successful operation, that this new type of machine has now definitely emerged from the experimental stage and has become an accepted piece of central-station equipment. Much remains to be done, however, now that some operating experience with these machines has been gained, toward simplification of the equipment and improvement of the general design. In developing the design described in the foregoing, the General Electric Company has endeavored to obtain a system that

would be as reliable and as nearly "foolproof" as possible, even at the expense of some complexity. Present developmental work is being directed toward the reduction in the number and size of the auxiliaries and in the simplification of the control equipment. A new type of shaft seal employing smaller shaft clearances than the present seal has been developed, which permits the use of smaller treating tanks and equipment than are used at present, and requires less hydrogen. A new purity indicator, with hydrogen and carbon dioxide scales, has been developed, which is more rugged than the indicator used on the earlier machines. A new stator frame design permits greater accessibility to the coolers for servicing, than the present design.

At present no hydrogen-cooled generators smaller than 28,125 kva at 3,600 rpm or smaller than 81,250 kva at 1,800 rpm have been built, or are under construction, by the General Electric Company. For sizes appreciably smaller than these, the gains with hydrogen cooling do not at present appear sufficient to justify the additional expense and complication involved in its use. However, further improvements in design, and increasing familiarity with hydrogen cooling on the part of the industry may eventually make desirable the extension of hydrogen cooling to include even the smaller sizes of machines. For the larger sizes, that is, above about 37,500 kva at 3,600 rpm and 75,000 kva at 1,800 rpm, it is probable that practically all future generators will be hydrogen cooled.

Appendix

Equations of the Shaft Sealing System

In the following are derived the equations for the hydrogen consumption and the hydrogen purity in the casing of a hydrogen-cooled generator provided with shaft seals of the oil-film type. These equations are based upon the theory of this type of shaft seal as given in the article of reference 5.

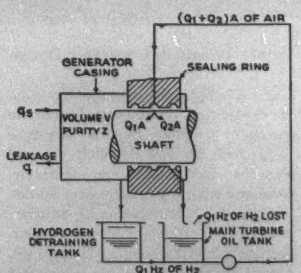


Figure 20. Schematic diagram of shaft-sealing system for hydrogen-cooled generators, using untreated oil

(a) Seals Supplied With Vacuum-Treated Oil

Referring to the schematic diagram of the sealing system in figure 2, let

Q_1 = number of cubic feet of oil flowing into the generator casing per hour (from both shaft seals)

Q_2 = number of cubic feet of oil flowing out on the air side per hour (from both shaft seals)

x = number of cubic feet of hydrogen contained in one cubic foot of oil coming from the vacuum tank at the time t

y = number of cubic feet of air contained in one cubic foot of oil coming from the vacuum tank at the time t

q = number of cubic feet of gas leaving the casing per hour as leakage at the time t

q_s = number of cubic feet of hydrogen of purity S entering the casing per hour at the time t

t = time in hours

H = solubility of hydrogen in the oil leaving the seal (that is, the number of cubic feet of hydrogen in one cubic foot of oil)

A = solubility of air in the oil leaving the seal (that is, the number of cubic feet of air in one cubic foot of oil)

z = per unit hydrogen purity in casing at the time t

$1-z$ = proportion of air in casing at time t

Z_0 = per unit initial hydrogen purity in drum (that is, $z=Z_0$ at $t=0$)

V = total volume of gas in drum and connected apparatus in cubic feet

S = proportion of hydrogen in gas supply per unit

$1-S$ = proportion of air in gas supply, per unit

P = absolute pressure corresponding to degree of vacuum treatment of oil, atmospheres

For the determination of the hydrogen consumption, referring to figure 2, note that the amount of gas in the oil flowing to the seals equals the difference between the amount of gas in the oil entering the vacuum tank and the amount of gas discharged from the vacuum pump. This can be shown to be

$$Q_1P[Hz+A(1-z)]+Q_2AP$$

which must equal

$$Q_1(x+y)+Q_2(x+y)$$

Equating the hydrogen terms and the air terms in these two expressions gives

$$x=Q_1\frac{PHz}{Q_1+Q_2} \tag{1}$$

and

$$y=\frac{Q_1PA(1-z)}{Q_1+Q_2}+\frac{Q_2AP}{Q_1+Q_2} \tag{2}$$

For the condition of constant gas pressure in the generator casing the following equation must be true

$$Q_1(x+y)+q_s=q+Q_1Hz+Q_1A(1-z) \tag{3}$$

Substituting the values of x and y from equations 1 and 2 in (3) and solving for q_s gives

$$q_s=q+Q_1[Hz+A(1-z)]-\frac{PQ_1}{Q_1+Q_2}\{Q_1[Hz+A(1-z)]+Q_2A\} \tag{4}$$

cubic feet per hour

for the amount of hydrogen that must be continuously supplied to the generator casing to make up for that lost through absorption in the sealing oil and that lost by leakage. For high degrees of vacuum and purity both P and $(1-z)$ are small so that the terms of equation 4 containing these quantities may be neglected and the equation for the approximate hydrogen requirement of the generator written as

$$q_s=q+Q_1Hz \text{ cubic feet per hour} \tag{5}$$

To determine the degree of hydrogen purity z that would be maintained in the generator casing with the system shown in figure 2, let the purity at time t be z, and at time $t+dt$ be $z+dz$. The latter purity can be shown to be

$$z+dz=\frac{Vz-[Q_1(Hz-z)+qz-q_sS]dt}{V} \tag{6}$$

Substituting the value of x from equation 1 an expression for dz/dt is obtained of the form

$$\frac{dz}{dt}=\frac{-z}{V}C+D \tag{7}$$

the solution of which is

$$z=\frac{DV}{C}+\left(Z_0-\frac{DV}{C}\right)\epsilon^{-\frac{Ct}{V}} \tag{8}$$

where

$$C=q+\frac{Q_1}{Q_1+Q_2}[Q_1(1-P)+Q_2]\times[H-S(H-A)] \tag{9}$$

and

$$D=\frac{S}{V}[q+Q_1A(1-P)] \tag{10}$$

The second term in equation 8 becomes zero for $t=$ infinity, so that the first term represents the final hydrogen purity in the casing. In figure 10 the hydrogen purity in the casing of the Logan generator, as a function of time following the starting-up of the generator, has been calculated from equation 8 for different values of P, for the value of q obtained in tests on this machine. In figure 11 the final values of purity from equation 8 have been calculated for different values of P and q. In these calculations S has been taken as 0.998. The rates of oil flow from the gas and air sides of the seal have been taken from tests as $Q_1=30$ and $Q_2=61.6$ cubic feet per hour, respectively. An average temperature of the seal oil of 42 degrees centigrade was used, for which the hydrogen and air solubilities were taken as $A=0.11$ and $H=0.041$, respectively. The casing volume V was taken as 1,000 cubic feet.

(b) Shaft Seals Supplied With Untreated Lubricating Oil

For this condition of operation figure 20 applies. For the condition of constant gas pressure in the generator casing we have, using the symbols given under (*a*),

$$q_s + Q_1 A = Q_1 Hz + Q_1 A(1-z) \tag{11}$$

whence

$$q_s = q - Q_1 z(A-H) \text{ cubic feet per hour} \tag{12}$$

for the amount of hydrogen continuously required by the generator with the seals supplied with untreated lubricating oil. For small values of q, q_s is negative, that is, hydrogen must be discharged from the casing to hold a constant pressure.

To determine the hydrogen purity in the generator casing under this condition, referring to figure 20 the purity at any time $t+dt$ can be represented by the equation

$$z+dz = \frac{Vz-(Q_1 Hz+qz-q_s S)dt}{V} \tag{13}$$

whence

$$\frac{dz}{dt} = \frac{-ZE}{V} + F \tag{14}$$

The solution of equation 14 is

$$z = \frac{F}{E}V + \left(Z_0 \frac{-FV}{E}\right)e^{-\frac{Et}{V}} \tag{15}$$

where

$$E = q + Q_1[H + S(A-H)] \tag{16}$$

and

$$F = q\frac{S}{V} \tag{17}$$

In figure 12 the hydrogen purity in the casing of the Logan generator, with untreated oil supplied to the shaft seals, has been calculated from equation 15 for two different values of oil flow to the hydrogen side of the seals, namely, $Q_1 = 30$ and $Q_1 = 48$ cubic feet per hour. For $Q_1 = 48$ cubic feet per hour, using an air solubility $A = 0.11$ in equation 15 gave values of purity z which checked the test values of purity exactly. This value of A was used, therefore, in calculating curve *b* in figure 12 and the curves of figure 10.

Solubilities of Air and Hydrogen in the Sealing Oil

In applying the equations of the foregoing section, the solubilities of air and hydrogen in the oil supplied to the shaft seals must be either known or assumed. The curves in figure 21 give the solubilities of air and hydrogen in transformer oil, which has a viscosity considerably lower than that of turbine oil and should therefore absorb gas more readily. Tests made by the writer indicated the solubility of air in turbine oil to be 10.8 per cent at 40 degrees centigrade, which agrees closely with the curve for transformer oil in figure 21.

In the calculation of figure 12 in the preceding section the assumption of an air solubility of 11 per cent, for oil at 42 degrees centigrade, was found to give transient values of hydrogen purity in the casing of the Logan generator which checked the test values exactly. This value for air solubility also agrees closely with the curve for transformer oil given in figure 21. However, calculation of transient values of hydrogen purity for the Cincinnati generator indicated that an assumption of an air solubility of seven per cent, for oil at 36 degrees centigrade, was required in order to check the test values of hydrogen purity. However, the turbine oil for the Cincinnati machine had a viscosity of 200 seconds Saybolt Universal at 36 degrees centigrade, as compared with a viscosity of 130 seconds Saybolt Universal at 42 degrees centigrade for the oil in the Logan turbine. Also the shaft speed of the Logan generator was 45 per cent higher than that for the Cincinnati generator, so that there was greater likelihood that all the air in the seal oil of the Logan machine would be given up to the hydrogen in the casing than would be the case for the Cincinnati generator.

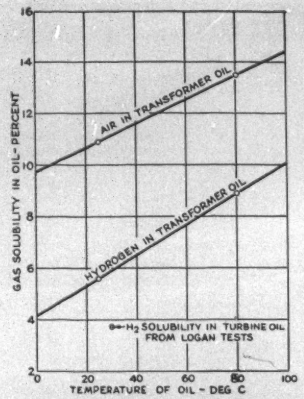


Figure 21. Solubilities of air and hydrogen in transformer oil at atmospheric pressure and at the temperature of the determination, for different oil temperatures, from tests by Rodman and Maude[9]

It may be deduced from the above that, for the solubility of air in the turbine oil to be used in the equations for the shaft seal, the curve for air solubility in transformer oil in figure 21 may be assumed correct if the oil is of low viscosity, and if the shaft speed is of the order of 12,000 feet per minute; however, for oils of high viscosity and at fairly low shaft speeds, the air solubility should be taken as 60–70 per cent of the values for transformer oil.

For determining the solubility of hydrogen in the turbine oil, tests made on the Logan generator at standstill with the shaft seals supplied with treated and with untreated oil were used. Substituting the test values of hydrogen consumption for these two conditions in equations 4 and 11 of the preceding section gave a value for hydrogen solubility of 0.037 at 30 degrees centigrade. This is 62 per cent of the solubility of hydrogen in transformer oil at this temperature. Assuming this same percentage to apply for other temperatures, the hydrogen solubility at the running temperature of 42 degrees centigrade was estimated to be 0.041 and this value was used in estimating the curves in figures 10 and 11.

Until more definite information is available regarding the solubility of hydrogen in turbine oil under the conditions which obtain at the shaft seals of a hydrogen-cooled generator, it may be considered sufficiently accurate to assume this solubility to be from 60 to 70 per cent of the solubility for hydrogen in transformer oil, as given by figure 21.

References

1. Hydrogen as a Cooling Medium for Electrical Machines, E. Knowlton, C. W. Rice, and E. H. Freiburghouse. AIEE Transactions, volume 44, 1925, pages 922–34.

2. Outdoor Hydrogen—Ventilated Synchronous Condensers, R. W. Wieseman. AIEE Transactions, volume 48, 1929, pages 1221–9.

3. The Application of Hydrogen Cooling to Turbine Generators, M. D. Ross. AIEE Transactions, volume 50, 1931, pages 381–6.

4. Hydrogen Cooling of Rotating Machines, C. M. Laffoon. AIEE Transactions, volume 55, 1936, pages 703–09.

5. Liquid Film Seal for Hydrogen-Cooled Machines, C. W. Rice. *General Electric Review*, volume 30, 1927, pages 516–30.

6. C. W. Rice, United States Patent No. 1,559,182.

7. Interchanging Hydrogen and Air in Hydrogen-Cooled Machinery, C. J. Fechheimer. *Electric Journal*, volume 28, 1931, pages 361–2.

8. M. A. Savage, United States Patent No. 2,099,575.

9. Effects of Gases in Transformer Oils, C. J. Rodman and A. H. Maude. American Electrochemical Society *Transactions*, volume 47, 1925, pages 71–92.

10. Limits of Inflammability of Gases and Vapors, United States Bureau of Mines Bulletin No. 279.

11. Hydrogen-Cooled Generators, E. H. Freiburghouse and D. S. Snell. *Power*, volume 82, number 8, 1938, pages 38–41.

12. Some Design Features of Hydrogen-Cooled Turbine Generators, D. S. Snell. *General Electric Review*, volume 42, number 2, 1939, pages 78–80.

Discussion

Sterling Beckwith: See discussion, page 34.

E. H. Freiburghouse (General Electric Company, Schenectady, N. Y.): The reliability of hydrogen cooling of large turbine generators has been thoroughly demonstrated. Referring to figure 18 of Mr. Snell's paper, it is seen that a continuous service record without interruption from any cause associated with the hydrogen-cooling features has been obtained on all of the generators of the design described in his paper. Nine of these machines are now in service. As a result of our operating experience with these machines, however, a number of simplifications and improvements have been found possible and these are being incorporated in the designs of our newer hydrogen-cooled generators. Some of these design changes and novel construction features will be mentioned in this discussion.

Figure 1 of this discussion shows the type of construction used with our latest hydrogen-cooled generators of the 3,600-rpm type, and the arrangement of the gas-

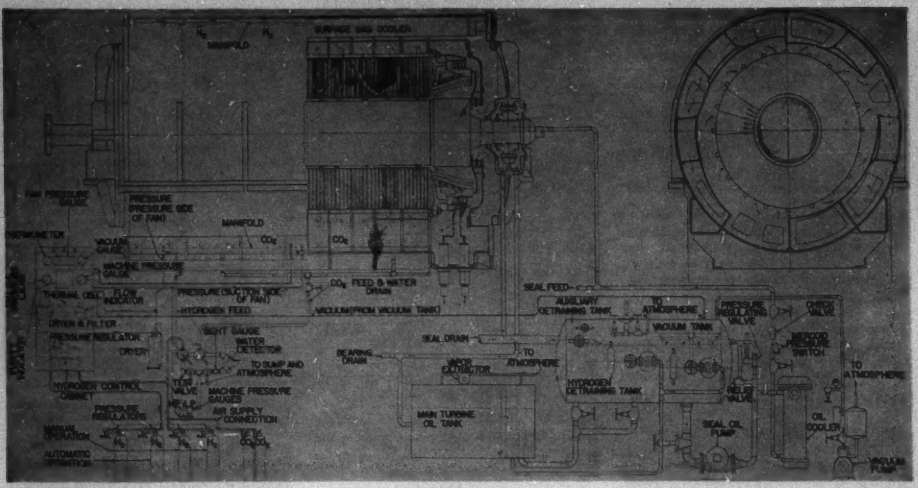


Figure 1

control and shaft-sealing systems. In this design the four gas coolers are located above the floor line, with the water connections at the extreme ends of the frame instead of at the sides, as in the earlier design. This construction permits easier cleaning of the cooler tubes than with the former arrangement.

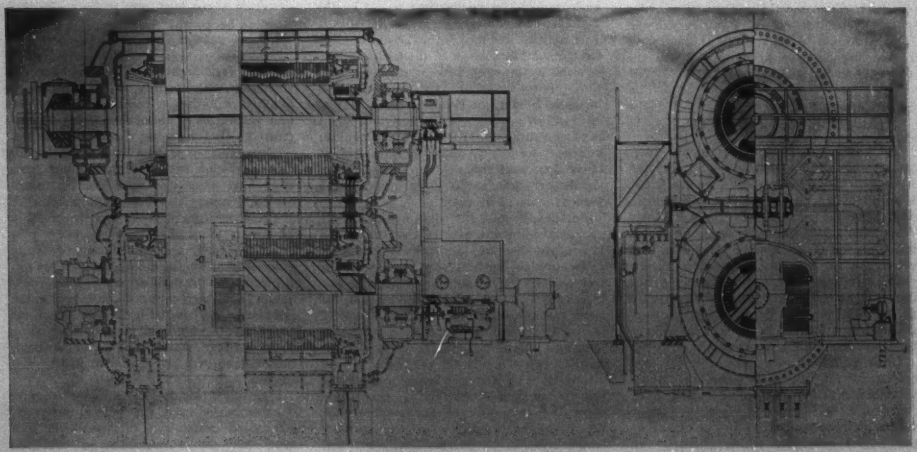
The arrangement of the gas control system shown in the above figure is appreciably simpler than the arrangement formerly used. Wherever possible, valves with diaphragm-packed stems are being used to reduce the possibilities of leakage. The solenoid gas-admission and scavenging valves, used with our present machines, have been replaced in the arrangement shown in figure 1 with diaphragm-type valves. This was done to avoid the leakage experienced with the solenoid valves, and also to eliminate the mercury relief valve.

The arrangement of the carbon-dioxide equipment shown in figure 1 is similar to that used with the machines now in service, and includes heating equipment which permits the carbon dioxide to be admitted to the generator casing as a gas. Carbon dioxide in the liquid form may be used thereby reducing the time for purging and eliminating the heating equipment, however, somewhat more carbon dioxide would be required.

Figure 2

Our laboratory has developed a new type of hydrogen purity indicator for use with hydrogen-cooled machines, which is more rugged and also more accurate than the indicator now used. This operates on the thermal-conductivity principle, as does the present indicator, but uses alternating instead of direct current, thus eliminating the need for the storage battery and rectifier.

The horizontal arrangement of shaft-sealing equipment shown in figure 1 is being used with a number of generators now under construction. This provides greater accessibility of the parts; however, a vertical arrangement of the treating tanks has been used wherever it was more suited to the station space. The different elements of either arrangement may be mounted on a common base and assembled as a unit.



One of the more unusual designs for hydrogen-cooled generators is that employed with the 137,500-kva vertical compound turbine generator set built for the Ford Motor Company, which is illustrated in figure 2 of this discussion. This generating unit, which is now being installed at Dearborn, Mich., consists of two separate hydrogen-cooled generators, each of 68,750 kva at 1,800 rpm, which are mounted one on top of the other. Each generator is provided with a double armature winding, and the windings of the two machines are paralleled through connections at one end as shown in the above figure. The casing of one generator is connected with the casing of the other through the conduits used for the electrical connections between the two armatures, so that the two casings are considered as one in filling or emptying the casings with hydrogen and carbon dioxide. However, each machine is provided with its own hydrogen purity indicator and a separate fan pressure gauge. Two gas coolers are provided with each generator, those of the upper generator being located in the bottom of the frame, while those of the lower generator are in the upper part of the frame. The hydrogen control panel, item 11, figure 2, is located in the side of the frame structure of the lower generator. A single set of treating tanks is provided for the shaft-sealing oil for both generators, also a single seal oil pump and vacuum pump.

This paper clearly indicates that much has been accomplished and important progress is being made in regard to the cooling of turbine generators by means of hydrogen. Operating experience is being rapidly accumulated, also further improvements in design and materials may be expected. It is, therefore, certain that hydrogen cooling will be an essential feature of large high-speed machines which are to be built, and generators of even larger power output per shaft will be possible in the near future.

Carl J. Fechheimer (consulting engineer, Milwaukee, Wis.): The desirability of using hydrogen as a cooling medium in large high-speed electrical machinery has been recognized since the presentation of the splendid paper by Knowlton, Rice, and Freiburghouse in 1925. Having done considerable work some years ago in the development of gland seals, devices for control and proportioning of parts when hydrogen cooling was beginning to be discussed, the paper by Mr. Snell is of especial interest to me.

It seems to me that the fear of an explosion has caused our engineers to be overly cautious. If an inert gas is used properly as an intermediary when changing from air to hydrogen or the reverse, it should not be necessary to burden the generator with the additional expense attended with making it explosion proof. Particularly with the large diameters associated with the large slower speed 1,800-rpm machines, it is essential to make the enclosing brackets with thick walls, probably with ribbing, and to curve them, so that they will withstand an explosion safely. I would inquire of the author whether consideration has been given to the design which will be sufficiently strong for ordinary operation only, and if so, by what percentage the cost of a large 1,800-rpm generator would thereby be reduced? Also, if the cost would thereby be reduced appreciably, and if the control equipment and shaft seals were simplified, as suggested by Mr. Snell, would it not be economically desirable to build hydrogen-cooled turbine generators for smaller ratings than recommended in the paper?

It is of interest to study table I on temperatures. The losses with air for 64 per cent of the load with hydrogen are 78 per cent higher as given by the gas temperature rise, and 87 per cent higher as given by the water temperature rise. The fairly close check between the two methods of computation is interesting. Undoubtedly, the windage loss was a very large percentage of the total loss. Even with considerably higher I^2R losses, the field temperature rise above the ingoing gas temperature was the same, but was ten degrees less with hydrogen, if referred to the ingoing water temperature. As it is the ingoing water that is the ambient, why not take the water temperature, and not the gas temperature, as reference?

The armature-coil temperature rises are even more favorable for hydrogen, they being only 75 per cent as high (referred to the ambient water), even though the I^2R loss was approximately 2.4 times as great. This considerable gain was undoubtedly due chiefly to the relatively high heat conductivity with hydrogen, which reduced the thermal drop from the copper to the iron, the transverse drop in the iron packages, and the heat transfer drop from the cooling surfaces to the cooling medium. Has Mr. Snell given consideration in the design to the feasibility of using thicker iron packages, and of increasing the current density in the armature copper, than would be employed in an air-cooled machine?

It seems from the test results that the usual ratio of rating for hydrogen to air cooling of 1.2 to 1.3 is entirely too conservative. If the data for this machine are typical of other hydrogen-cooled turbine generators, even 50 per cent increase in rating is conservative.

In figure 9 the use of diffusers to improve the efficiency and increase the pressure of the centrifugal fan is interesting, and was considered many years ago. It was found that propeller fans were more efficient, were not so much restricted at entrance as centrifugal fans, and could be applied to larger sizes of machines. It is worthy of note that with the very high peripheral velocities of the centrifugal fans, more pressure can be developed than is necessary; the result is that the fans are not operated at the most favorable point on their pressure-volume curves. Is it not likely, as shown in table I, that the high gas temperature rise when air is used, is largely due to the high fan pressure and rather low fan efficiency? If so, perhaps the ratio of ratings would not be so high (as suggested in the preceding paragraph) if the temperature rise of the air when passing through the fans were reduced?

As indicated in figure 9, a number of hollow metal pads between lamination packages, were used for the water coolers. The details of construction are not entirely clear and I would inquire whether the pads interfered with the flow of hydrogen, and whether the thermal drops from laminations to water were appreciably altered, as compared with the usual finned surface cooler.

Perhaps one thing that has helped to bring the construction of hydrogen-cooled machines to the forefront, is that now we can calculate quite closely the fans, pressures and volumes, as well as the distribution of the cooling medium throughout the machine, which could not have been done a comparatively few years ago.

It seems that today, instead of hydrogen-cooled machines being hazardous, they are actually the safest machines, because there is no internal gas to support combustion, there is negligible damage from corona, and they are as clean after years of service as when first placed in operation.

P. L. Alger (General Electric Company, Schenectady, N. Y.): When hydrogen cooling for electrical machinery was first proposed, the chief objection to its use was the fear of an explosion. Tests made to determine the pressure developed in an explosion of the most explosive hydrogen-air mixture, initially at atmospheric pressure, indicated that the explosion pressure, for a machine assembled with core and windings, would not exceed 50 pounds per square inch. The theoretical explosion pressure, for no heat loss to the surroundings, is 180 pounds. Since, however it is not difficult to construct the frame of the machine to withstand a force of 200 pounds per square inch, it is apparent that there is

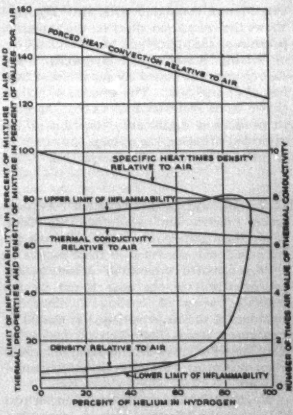

FORCED HEAT CONVECTION RELATIVE TO AIR
SPECIFIC HEAT TIMES DENSITY RELATIVE TO AIR
UPPER LIMIT OF INFLAMMABILITY
THERMAL CONDUCTIVITY RELATIVE TO AIR
DENSITY RELATIVE TO AIR
LOWER LIMIT OF INFLAMMABILITY
LIMIT OF INFLAMMABILITY IN PERCENT OF MIXTURE IN AIR, AND THERMAL PROPERTIES AND DENSITY OF MIXTURE FOR AIR
NUMBER OF TIMES AIR VALUE OF THERMAL CONDUCTIVITY
PERCENT OF HELIUM IN HYDROGEN

Figure 3

very little to fear from an explosion in a hydrogen-cooled machine.

Nevertheless, it is interesting to consider other gases which could be used for cooling that are not subject to these explosion risks, slight as they are, thus promoting economy in methods of installation and handling. An obvious possibility is the use of helium. The light weight of helium gives very low windage losses, but its materially higher cost and its inferior cooling properties make it undesirable for use as a pure gas. It therefore occurred to me that the properties of a mixture of helium and hydrogen should be investigated, in the hope of obtaining a gas free from explosion risk, that would pre-

serve practically all of the advantages of pure hydrogen. The results of a theoretical study of this subject by Doctor Saul Dushman and D. S. Snell are presented in the two accompanying figures.

Figure 3 of this discussion shows the limits of inflammability of a mixture of hydrogen and helium, also the thermal properties of

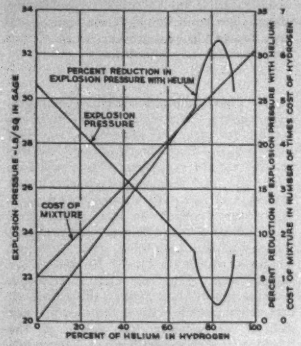

PERCENT REDUCTION IN EXPLOSION PRESSURE WITH HELIUM
EXPLOSION PRESSURE
COST OF MIXTURE
EXPLOSION PRESSURE—LB/SQ IN GAGE
PERCENT REDUCTION OF EXPLOSION PRESSURE WITH HELIUM
COST OF MIXTURE IN NUMBER OF TIMES COST OF HYDROGEN
PERCENT OF HELIUM IN HYDROGEN

Figure 4

the mixture compared with air. Figure 4 shows the calculated effect on the explosion pressure at the upper limit of inflammability, of mixing helium with hydrogen. The curves were calculated for an assumed heat loss of 25 per cent. The amount of helium shown to be required, and its cost, in order to produce a significant reduction in the explosion pressure, are so large, however, as to make this procedure unattractive.

C. F. Hill and L. J. Berberich (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The operating experience described in these papers on hydrogen-cooled generators indicates that hydrogen will in the near future be the generally accepted cooling medium for machines of the larger ratings. It should be mentioned again that electrical insulation is subjected to fewer deteriorating influences when operating in hydrogen as compared with air.

We should like to re-emphasize one or two of these. The effects of oxygen, ozone, and oxides of nitrogen, the last two being produced only under corona conditions, are completely absent. These phenomena have been discussed in previous papers and need be only mentioned here. But even more important, is the problem of moisture absorption by the insulation which can be almost completely eliminated in the hydrogen-cooled machine.

Here the only source of moisture is from the oil supplied to the hydrogen seals. The moisture is, of course, introduced into the lubricating oil system by the turbine. When moisture-laden oil is passed into the seals, which run in the neighborhood of 100 degrees centigrade, a considerable amount of water is vaporized into the machine. This water vapor acts as a contaminant to the hydrogen and increases the apparent hydrogen consumption. Mr. Snell in his paper stresses the contaminating influence of air from the seal oil, but it is our experience that moisture can also be a serious diluent of the hydrogen.

This moisture problem has been eliminated by the combination of an oil vacuum treating unit and a gas drying unit which are described by Messrs. Ross and Sterrett. The simple vacuum-treating unit reduces the water content of the oil to less than 0.003 per cent by weight. With added complications, the vacuum system could be made to reduce the moisture content still lower. But even at very low concentrations, some moisture is always vaporized from the oil in passing over the seals which will gradually build up moisture concentration in the machine and this will eventually increase the hydrogen consumption. This, together with the possibility of failure of the oil vacuum treating system, justifies the addition of the exceedingly simple activated-alumina gas dryer described by Messrs. Ross and Sterrett.

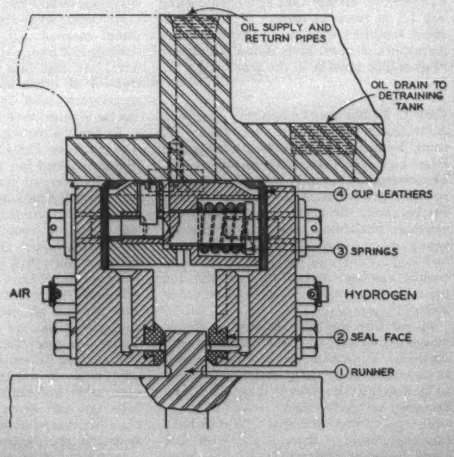
We have studied one of these machines and the results may be of interest. Actual determination of the moisture content of the gas in a 50,000-kw machine which had been in operation for some time has been made. With the vacuum-treating unit and dryer in operation the moisture content was approximately 0.01 gram per cubic foot of gas. This corresponds to a relative humidity of 0.4 per cent at machine temperature of 55 degrees centigrade (machine was only partially loaded at time of test), a dew point in the neighborhood of −25 degrees centigrade, and volume concentration of water vapor of approximately 0.06 per cent. The effectiveness of this system of moisture and air removal is attested by the fact that the hydrogen consumption for this machine is only 20 cubic feet per day. A similar test was made on the same machine with the moisture elimination system not in operation and a water content of roughly 1.0 gram per cubic foot gas was found. This corresponds to a relative humidity approximately 25 per cent at 55 degrees centigrade, a dew point of 30 degrees centigrade and volume concentration of water vapor of 4.8 per cent. Under these conditions the hydrogen consumption was very high and water was condensed from the gas at the coolers which were operating approximately 10 degrees centigrade below the dew point. The necessity of removing moisture from the oil going to the seals is thus indicated.

Returning again to the electrical insulation, the combined oil-treating and gas-drying system so effectively removes moisture and air from the oil that the insulation may be considered almost hermetically sealed in an inert medium. The problems caused by the effects of ozone, oxides of nitrogen, moisture, and accumulation of dirt are all eliminated. The performance of the insulation in hydrogen should therefore be far better than in air.

S. H. Mortensen (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): The authors of the papers on hydrogen-cooled turbine generators have so admirably covered the design and operating problems incidental to hydrogen-cooling of turbine generators, that I find nothing to add except a description of the Allis-Chalmers company's hydrogen-shaft seal and a discussion of its effect upon certain faces of the generator operation.

The Allis-Chalmers company's shaft seal is shown in figure 5 of this discussion and consists of a small runner, item 1, provided on the generator shaft at each end of the machine close to the main bearing, and

Figure 5. Shaft seal



against each face of the runner a conventional babbitt thrust bearing, item 2, is held by springs, item 3, permanently set to give a pressure equal to about a third of the normal capacity of the bearing. Around the inner periphery of each thrust bearing, but separated from it by a groove, is a continuous babbitt face about an eighth of an inch wide. During operation this continuous face provides the required seal, since it is

separated from the runner by only the thickness of the oil film in the thrust bearing. Oil under pressure is circulated around the flange between the two thrust-bearing faces to provide cooling and lubrication and to oppose the pressure of the hydrogen at the small clearance between the continuous babbitt face and the flange. The oil pressure counterbalances the spring pressure so that resulting bearing load is very low. Cup leathers, item 4, are provided at the outer periphery of the oil chamber to retain the oil and provide flexibility.

The Allis-Chalmers type of seal is suitable for operation with hydrogen pressures from zero up to ten pounds per square inch without oil or seal adjustments.

As this type of seal provides an air-tight joint, air or gas can be removed from the generator by evacuation. This makes it practicable to simplify the scavenging process described by authors to the extent of eliminating the use of carbon dioxide and offering advantages such as;

1. No carbon-dioxide or other inert gas is required for scavenging generator.
2. Since interchange of hydrogen and air takes place at one fifth of an atmosphere or less, only about one fifth as much excess hydrogen above one volume is required.
3. Extra pipes to drain all "pockets" of carbon-dioxide are not essential.
4. Less time is required to empty or fill generator with hydrogen.
5. The filling operation is simplified.

Operating experience, over a period of months, further shows that the sealing oil volume which gets into contact with the generator hydrogen is so small that oil treatment becomes unnecessary except for its passing through a hydrogen detraining tank before it is returned to the oiling system.

It is expected that additional operating experiences will result in further simplifications in the application of hydrogen as a ventilating medium.

Philip Sporn (American Gas and Electric Service Corporation, New York, N. Y.): Early in 1935 studies indicated the desirability of installing at Logan, W. Va., a 40,000-kw 3,600-rpm high-pressure superposition turbine, in order most economically to develop and increase the capacity of the existing power plant at this location. At that time the manufacturer stated that cooling of the rotor for a generator of this size and speed could be accomplished only by utilizing hydrogen ventilation. Following our extensive and successful experience with seven large-capacity hydrogen-cooled synchronous condensers then in service on the American Gas and Electric Company system, we unhesitatingly accepted hydrogen cooling for this new generator unit. In the case of synchronous condensers, the bearings are entirely enclosed in the outer shell, and therefore the problem of sealing the shaft against gas leakage is not encountered. However, extensive tests and factory operating experience with the oil seal at Schenectady over a period of years, provided a basis for anticipating satisfactory performance from this shaft-sealing arrangement in power-station service.

The Logan generator went into operation as a hydrogen-cooled machine on December 2, 1937, and from that time until February 28, 1939, the unit has run a combined total of 232 days. The running time lost during this period has not been occasioned by any trouble or maintenance in connection with the generator proper or its gas sealing system. No difficulty of any great importance has been experienced with the shaft-sealing system and its accessory equipment. No failure to maintain the seals has occurred at any time. As of February 28, 1939, this seal system had operated 308 days. We are now maintaining a purity varying from 99 to 100 per cent and the gas consumption is averaging approximately 40 cubic feet per day. The delivered cost of this gas, including handling of the cylinders, amounts to approximately 2 cents per cubic foot, so that the yearly cost on this basis is less than $300.

Mr. Snell describes in his paper the pad cooling arrangement for direct water cooling of the stator. Plant condensate was used as make-up for this pad liquid system. In order to eliminate the possibility of air pockets in the pads, it is necessary to obtain a high vacuum before filling with condensate. In this respect some difficulty was experienced initially but by circulating the pad liquid for some time and by wasting a portion from the overhead expansion tank, it was possible to remove practically all of the air still remaining in the pads. The operation of the system has been entirely satisfactory.

Mention is made of operation at gas pressures as high as 15 pounds per square inch. The Logan unit has been run for short periods at these higher pressures with satisfactory performance of the shaft-sealing system and without obtaining excessive consumption of gas. We have had considerable experience with the operation of hydrogen-cooled synchronous condensers at pressures up to and including 15 pounds per square inch. We hope to present detailed operating data covering such performance in a coming paper before the Institute.

D. S. Snell: I wish to thank Mr. Fechheimer for his interesting and valuable discussion. Mr. Fechheimer has contributed much to the development of hydrogen cooling and his comments on the subject are welcomed. As to the saving effected with hydrogen-cooled generators of the 1,800-rpm type through making the machine structure strong enough only for normal operation, but not strong enough to withstand an explosion, I believe that for the type of construction employed with our hydrogen-cooled generators no saving would be obtained. For with a construction in which the generator bearings are supported in the end shields, a construction that is rigid enough for ordinary operation is also strong enough to withstand an explosion. At the present time the cost differential between the hydrogen-cooled and the air-cooled machine is principally due to the cost of the auxiliary equipment, and as this cost does not vary greatly with different sizes of machines, it is difficult at the present time to justify the use of hydrogen cooling for generators in sizes much smaller than the minimum sizes mentioned in the paper.

Regarding Mr. Fechheimer's proposal that ingoing water temperature rather than ingoing gas temperature be used as the reference for basing temperature rises for hydrogen-cooled machines, we have given considerable thought to this matter but still feel that the use of the ingoing gas temperature offers the best basis for making guarantees on this type of machine. The use of the ingoing gas temperature as a basis for temperature rise allows an accurate comparison between different machines as the true rise of the machine alone is obtained, whereas if the ingoing water temperature were used as a basis, a designer could skimp the design of the generator and use an extra large cooler, obtaining the same over-all temperature rise with this machine as with a machine of more liberal design. Obviously the machine with the lower temperature rise within itself is the more liberal design.

Also, since it is easy to test the coolers and the generator separately, there is little or no reason to combine the two in one over-all guarantee, and especially is this true due to the fact that the generator is the major portion of the investment and the more critical.

The Institute at the present time has adopted the ingoing gas or air as a basis for the ambient temperature on which rises should be predicated, and we can see no reason for the Institute's making two different standards for large rotating equipment because one happens to be enclosed and the other an open machine, as basically the temperature rises, which are satisfactory for one machine are applicable to the other type.

Regarding the thickness of the stator iron packages and the armature current density in the hydrogen-cooled machine, both these quantities have been increased over their values for the air-cooled machine.

Mr. Fechheimer's suggestion that the increase in rating of a generator by the use of hydrogen should be considerably greater than the 20 per cent mentioned in the paper, based on the data given in table I, neglects the fact that the hydrogen-cooled generator must be proportioned differently than the air-cooled machine, to obtain the same electrical stability. If this change in design is considered it will be found that the increased output per pound of material with hydrogen will be of the order of 20 to 25 per cent.

Regarding the use of diffusers in conjunction with the centrifugal fans employed with these machines, while these are generally provided with air-cooled generators they have been omitted from many of the hydrogen-cooled machines for the reason that fan efficiency is relatively unimportant in a hydrogen-cooled machine, while the reduction in machine length obtained by omitting the diffusers is of value. This omission results in a rather high windage loss and temperature rise of the air when the machine is operated in air, as Mr. Fechheimer has observed in connection with table I; however, since these machines are intended principally for operation in hydrogen, this feature is not considered important. As to the relative merits of centrifugal and propeller fans, we recognize that while the propeller fan has a slight advantage in efficiency it also requires a greater amount of axial space on the shaft for its support, thus increasing the distance between bearing centers.

Referring to Mr. Fechheimer's inquiry as to the construction of the machine illus-

trated in figure 9, figure 6 of this discussion illustrates the construction of the metal pads which are employed for removing the heat from the stator core and the cooling gas. The pads of the plain type are used in the end sections of the stator core and remove the generated heat by direct conduction to the cooled pad. The finned pads are used in the center part of the core and

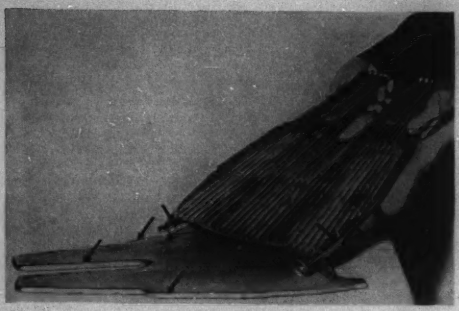


Figure 6. Monel-metal cooling pad for hydrogen-cooled generator, copper-brazed

Arrows indicate brazed joints

absorb heat both by conduction through contact with the laminations, and by convection, through passage of the heated gas from the air gap to the back of the core between the fins. The finned pads take the place of the surface gas coolers used with the ordinary type of generator. The fan pressure required to ventilate this type of machine is practically the same as is required with the ordinary type, for the same volume of gas circulated.

It is true, as Mr. Fechheimer suggests, that the development of the hydrogen-cooled machine has been accelerated by the progress previously made in methods of calculating fan performance and ventilation characteristics, and also, I would add, in methods of predetermining the thermal behavior of electrical machines. For much of this progress we are indebted to the researches of Mr. Fechheimer.

The shaft seal described by Mr. Mortensen possesses many desirable features. Several years ago we tested a seal of a somewhat similar type, in which a stationary carbon ring pressed axially against a runner carried on the shaft. Trouble was experienced, however, through air being pumped into the generator casing between the ring and runner by centrifugal force. In Mr. Mortensen's seal this pumping action is prevented by supplying lubricant to the rubbing surface under pressure.

While it is desirable to eliminate from the sealing system as many auxiliaries as possible, the elimination of the vacuum tank, as suggested by Mr. Mortensen has certain disadvantages. Without the use of vacuum-treated oil in the shaft seals, the hydrogen purity in the generator casing will decrease, even if at a slow rate, and the operator must manually scavenge the casing at intervals in order to maintain the desired hydrogen purity. If the oil is vacuum treated, however, no scavenging is required. Also, the vacuum treatment of the sealing oil, aside from its value in the operation of the hydrogen system, is of definite value with respect to the operation of the bearings of the turbine generator set, since vacuum treatment of oil removes impurities and thereby prolongs its life. Considering that the vacuum tank requires little space and practically no servicing, it does not seem that the elimination of this device offers as many advantages as its retention.

The evacuation of the generator casing before filling with hydrogen, or when emptying, as proposed by Mr. Mortensen, has some advantages over the use of an inert gas. However, to evacuate the casing requires that the generator be at rest, whereas the inert gas may be introduced with the generator rotating, which is frequently done to save time.

Messrs. Hill and Berberick mention the problem of contamination of the hydrogen by moisture given up from the sealing oil as being of equal importance to the problem of contamination by air from the oil. While this is probably true where the temperature of the oil leaving the seals is in the neighborhood of 100 degrees centigrade, it is not the case where the temperature of this oil is approximately 60 degrees centigrade, as is the case with the type of seal described in my paper. Since the radial shaft clearance of this seal is the same as that of the bearing the energy loss in the oil film is low compared with the oil flow so that only moderate oil temperatures are obtained. This precludes the possibility of moisture being vaporized out of the oil into the generator.

Mr. Beckwith suggests the elimination of the hydrogen relief valve. In the system described in my paper a relief valve of the mercury type is used to prevent the discharge of hydrogen into the air detraining tank in the event of excessive pressure in the casing. In our later designs a diaphragm type of relief valve is used, which serves also for scavenging. In our case this valve can hardly be dispensed with.

The hydrogen requirement for these machines has been found to vary approximately with the square root of the hydrogen pressure, as stated by Mr. Beckwith, although theoretically the part of the hydrogen requirement due to absorption in the sealing oil should vary about directly with the absolute pressure. The discrepancy is probably due to a slight opening-up of the casing joints at the higher pressures. Tests on the Logan 50,000-kva generator showed a hydrogen requirement of 40 cubic feet per day at one-half pound pressure and 300 cubic feet per day at 15 pounds.

Mr. Sporn describes operating experiences with the Logan generator, which was one of the first hydrogen-cooled generators to be placed in service. It is gratifying to us that this machine, which embodied two radical departures from conventional design-hydrogen cooling and pad cooling—should have operated practically without trouble since installation. Mr. Sporn's company has been a pioneer in the use of hydrogen-cooled machinery, having installed in 1928 one of the first hydrogen-cooled synchronous condensers and in 1937 one of the first hydrogen-cooled generators. His faith in this new development has contributed largely to its success and it is gratifying to us to see that his confidence in hydrogen cooling has been justified.

Mr. Alger mentions a theoretical study made to determine the desirability of using a mixture of helium with hydrogen to reduce the explosion pressure. At the time this investigation was made the cost of commercial helium was approximately six times the cost of hydrogen. Since then the cost of helium has been greatly reduced and it can now be obtained for approximately twice the cost of hydrogen. Even with this reduction in cost, however, the use of helium as a cooling agent is not considered desirable since its cooling properties, as explained in the paper, are considerably inferior to those of hydrogen. Since the type of generator construction and the shaft-sealing and gas-control equipment would be substantially the same whichever cooling medium were used, and the helium-cooled generator would be appreciably larger than the hydrogen-cooled machine for a given output, it will be evident that the use of helium is not economically advantageous.

Mr. Freiburghouse has mentioned some of the recent improvements that have been made in the design of the hydrogen-cooled generator, also some of the details of construction of the 137,500-kva hydrogen-cooled generating set for the Ford Motor Company. This generator set has recently been placed in service with hydrogen. The shaft seals used with these generators are of a different type from those used with our earlier generators and consist of metal rings bearing radially on the shaft, the rings being supported in a housing attached to the end shield. This type of seal requires less oil than the type described in the paper, so that smaller treating tanks and equipment may be used.

Besides the Ford generators, two other hydrogen-cooled generators have been placed in service by our company since my paper was written. We have now 12 of these machines in operation, their combined rating being 770,000 kva. The largest 3,600-rpm machine is rated 66,667 kva while the largest 1,800-rpm generator is rated 176,470 kva. A total of 19 hydrogen-cooled generators are under construction at the factory, with a combined output of 1,035,000 kva. One of these units is rated 50,000 kva at 3,000 rpm and will be installed at Buenos Aires. This is the first hydrogen-cooled generator to be sold for foreign installation. The growing popularity of this new type of generator indicates that the former apprehensions regarding hydrogen cooling have been largely dissipated by the successful operation of the units now in service and that the many advantages of hydrogen cooling are becoming widely recognized.

Some Factors in the Mechanical Design of High-Speed Turbogenerators

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Synopsis: The following paper deals with the approach and the results obtained by advanced engineering technique applied to a few of the problems in large high-speed turbogenerator rotor design. Research and design details incidental to yoke vibrations, application of hydrogen for ventilation, etc., may be dealt with in a future paper.

PROGRESS in steam-turbine design combined with the rapid upturn in power requirements experienced in 1936–37, created a demand for high-pressure high-temperature steam-turbine units of large capacity. It is desirable to operate this type of prime mover at the maximum practicable speed and a number of large air- or hydrogen-cooled 3,600-rpm 60-cycle machines were ordered from the company the writers are associated with. As our previous experience was limited to machines of capacities below 9,500 kva, the larger machines presented further problems, making it advisable to check experimentally the reliability of standard and advanced calculating methods to insure reliable machines, and the ground work for the development of larger capacity machines.

As an example of recent-type two-pole 60-cycle generator construction figure 1 may serve, which depicts a 43,750-kw air-cooled turbine generator with a rotor diameter of 33¼ inches. To limit the axial length of this machine it was designed with external blowers mounted inside the yoke above the armature. The cooling elements for the ventilating air were also made part of the yoke, thereby reducing the external generator space requirements to a minimum.

To keep this paper within bounds, it will deal only with three of the many factors investigated, which, in the following, are discussed in the order of their original consideration:

1. The determination of critical speeds[1,2] by test for comparison with calculations for symmetrical- and unsymmetrical-section two-pole rotors.

2. Stress analysis of the generator rotor body.

3. Analysis of the lubrication characteristics of the generator bearings to determine maximum bearing efficiencies.

A. Vibration Analysis of Long Rotors

To investigate the accuracy of critical-speed calculations and the vibration behavior of long turbogenerator rotors, a shaft model was constructed having scalar dimensions similar to 3,600 rpm turbogenerators. This rotor model was operated at various speeds, and the vibrations of the shaft and pedestal supports were observed and recorded.

The tests were made for two conditions of the model; first, as a round, symmetrical rotor; and, second, as a two-pole slotted rotor. The maximum shaft diameter was six inches with a 12-foot span between bearing centerlines. It was mounted in 2½-inch by six-inch bearings, and driven by a motor having a maximum speed of 4,000 rpm. The weight of the unslotted rotor was 815 pounds and its moment of inertia 63.63.

Following the tests on the round rotor, slots were machined in the shaft model, to obtain a cross section having two moments of inertia at right angles, approximately to the scale of the average

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The co-operation of the steam-turbine department, Allis-Chalmers Manufacturing Company, and the aid of Charles D. Wilson are respectfully acknowledged in the measurement and analysis of the lubrication tests.

1. For all numbered references, see list at end of paper.

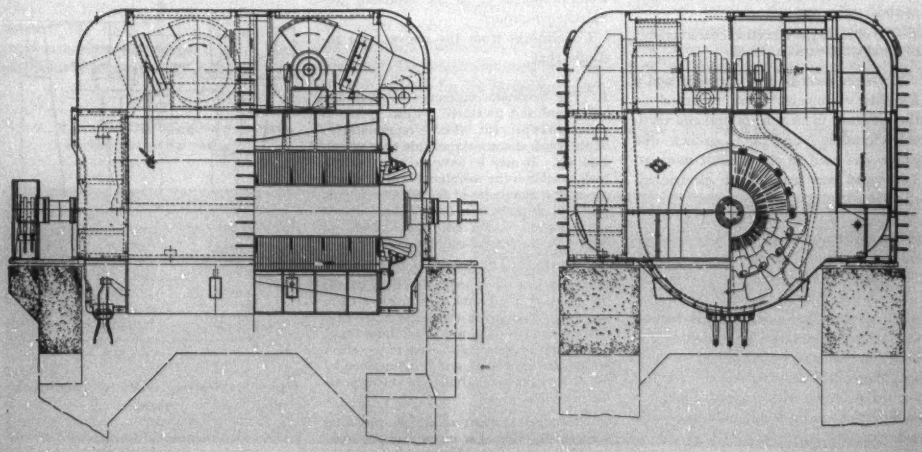

Figure 1. Outline of 43,750-kw turbogenerator

Figure 2. View of model shaft—slotted

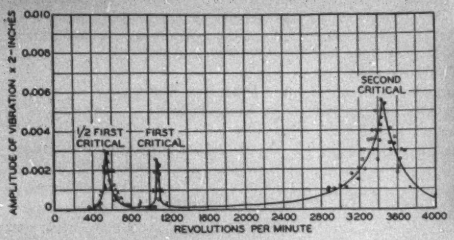

Figure 3. Amplitude-frequency graph of model-shaft vibrations

Two-pole slotted rotor

Figure 4. Two-pole turbogenerator rotor

two-pole generator rotor. The slots were cut one-fourth inch wide and one inch deep, spaced $^1/_{28}$ of a circle, with ten slots per pole. The shaft was operated as before and the vibrations observed. A photograph of the shaft after machining is shown in figure 2.

The weight of the slotted rotor was 695 pounds; its maximum moment inertia 52.27; its minimum inertia 42.17.

As stated, the objects of the tests with the model rotor were:

1. To determine experimentally the first (n_1) and second (n_2) critical speeds for comparison with calculated values;

2. To measure the effective flexibility of the pedestals; and

3. To observe the vibration characteristics of the shaft at various speeds.

A Geiger recording vibrograph[3] and a Karelitz vibrometer[4] were mounted on the pedestals to measure lateral and vertical vibrations, and a $^1/_{1,000}$-inch dial gauge was used to check shaft motions. The speed was read on an electric tachometer.

As originally set up, the vibrations of the symmetrical shaft were too small to enable observation of the critical speeds. The rotor was unbalanced a sufficient amount to obtain measurable vibrations. After slotting the rotor for the second tests, it was necessary to straighten the shaft, and balance was obtained by placing plugs in balancing holes. At the final balance, the critical speeds could not be detected, and a slight unbalance was restored.

The calculated and measured critical speeds compared as follows:

	Calculated	Test: Horizontal	Test: Vertical
Symmetrical rotor	$n_1 = 1{,}060$	$n_1 = 1{,}080$	1,085
	$n_2 = 3{,}400$	$n_2 = 3{,}280$	3,370
Slotted rotor	$n_1 = 1{,}072$	$n_1 = 1{,}074$	
	$n_2 = 3{,}497$	$n_2 = 3{,}430$	

In figure 3 are plotted the values of the measured total vibration of the outboard pedestal in a horizontal direction at various speeds for the slotted unsymmetrical rotor. The existence of three critical vibrations were established with no other disturbances in the running range. The amplitudes of vibration were proportional to the arbitrary unbalance conditions.

Conclusions from the above tests indicate that:

1. The maximum difference between the calculated and measured critical speeds is about three per cent, which is representative of the general accuracy of this type of calculation. It may be assumed that on full-scale machines the calculated critical speeds are within the limits of test measurements. The average moment of inertia of the slotted rotor section is the effective moment of inertia for the critical-speed calculations.

2. For the symmetrical rotor, the pedestal flexibility has no appreciable effect on the first critical speed, and only about a three per cent reduction in the horizontal direction over the vertical at the second critical. This quantity is representative of the effect on full-size apparatus, and is maintained by requiring rigid foundations and sturdy bearing pedestals.

3. Running the shaft at various speeds to observe the vibration characteristics indicated that no appreciable vibration occurred except in the immediate vicinity of the criticals. For the slotted rotor, a subcritical was evident at one-half the first critical speed, due to the variable moment of inertia of the shaft. As shown in the vibration curve, figure 3, the slotted rotor would operate as well above the second critical speed as between the first and second. Thus it may be further concluded that very long turbogenerator rotors operating normally above the second critical speed would be entirely practical from a vibration, balancing, and critical-speed standpoint. The present critical speeds for 3,600 rpm turbogenerators could be reduced from 1,600 and 5,000 rpm, respectively, to 900 and 2,700 rpm, making possible a considerable increase in generator capacity with

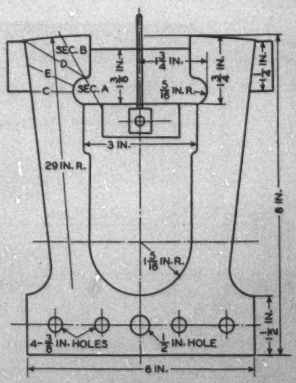

Figure 5. Working sketch of photoelastic model

Transparent Bakelite

added flexibility in design. Such a trend may be anticipated for future consideration

B. Rotor Stress Analysis

The electrical output of a turbogenerator is roughly proportional to the amount of field copper which may be safely imbedded around the periphery of the rotor. Figure 4 shows the general construction of the type of rotor considered. The teeth between the radial coil slots must be adequate to carry magnetic flux, withstand mechanical stresses, and also carry vent ducts.

To obtain the most efficient and safe design, the stress in the rotor must be accurately known at every point, and the maximum stresses at overspeed of 20 per cent must not exceed the elastic limit of the material.

The area having the most complex stress distribution occurs at the outer extremity of the teeth, at which point slot wedges transfer the centrifugal forces of the winding to the teeth. Further, the bore stress of the central exploration hole is usually of great importance. The following paragraphs discuss the manner in which the stresses were analyzed to obtain the most effective design.

1. Design of Rotor Teeth and Wedges

To determine accurately the centrifugal stress distribution in the rotor teeth and wedges due to the windings, the photoelastic method of analysis was applied. Several transparent Bakelite models were made of the proposed designs to a scale approximately twice full size for use in a large photoelastic polariscope.[5] With load applied under the wedge the respective stress distributions showed the effect of the changes in curvature of the slot wedge fillets. The photoelastic isochromatic pictures determine the difference of the principal stresses while the sums of the principal stresses were measured at points on the sections by means of a thickness-indicating device employing a Huggenberger Tensometer.[6] Configurations giving unpredictable stress concentration were discarded.

A sketch of the final wedge model, its general dimensions, and method of loading in the testing machine is shown in figure 5. A steel bar is clamped between the vent wedges to simulate the built-in condition of the rotor section.

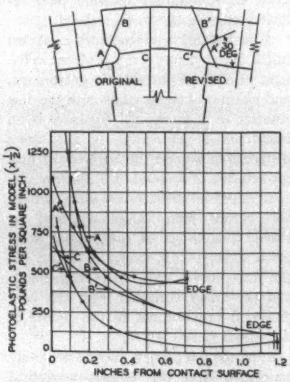

Figure 7. Curves of maximum shearing stresses for original and revised sections

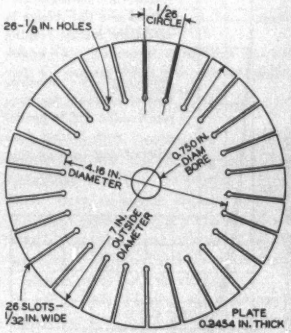

Figure 8. Sketch of photoelastic model of rotor section as rotating disk

The photoelastic stress distribution[7] for the final tooth and wedge element is shown in the isochromatic picture, figure 6. The stress concentrations along the contact surfaces are entirely removed and a uniform distribution of loading is obtained. The maximum shear stresses on these sections for the preliminary and final designs are shown in figure 7, the latter being indicated by prime letters. An immediate comparison of the effectiveness of the final design was observed by counting the number of bands or fringes proportional to the shearing stress. The maximum tensile stress at the fillet of the tooth, section *C*, was only slightly lowered by the increase of the fillet radius.

To further decrease these stresses the surface area in contact under pressure was increased by slightly reducing the slot width above the wedge, and the vent slot was made narrower to increase the minimum tooth section. The wedge stresses were not adjusted further since materials for that section are available with any desirable elastic limit.

Standard calculations for the revised design, considering compression, bending, and shear, checked very closely with the photoelastic stress analysis. For the minimum section (section *C*) of the tooth in tension, however, the photoelastic stresses were approximately 30 per cent higher than the calculated stresses; thus it would be assumed that the

Figure 6. Photoelastic picture—revised winding slot wedge shape

Figure 9. Photoelastic picture—rotating disk at 9,200 rpm

stress concentration at the fillet is 1.3.

The applications of these tests in the design of machines have resulted in structures which are completely and accurately analyzed, and for which the maximum stresses do not exceed the elastic limits of the forging materials. Further adjustments may be made in the development of larger machines based upon the data obtained in this analysis.

2. Rotor Bore Stresses

In determining the tangential stresses at the surface of the exploration hole bored in the center of turbogenerator rotor forgings, it is ordinarily assumed that the centrifugal loads on the teeth and the teeth themselves act as a uniformly distributed external loading on a thick cylinder equivalent to the net rotor section. On the stresses obtained in such a thick cylinder are superimposed the stresses due to rotation of the net rotor section as a rotating disk.

To verify the accuracy of the above assumption a model of a section of a 37-inch-diameter turbogenerator rotor body having $7^1/_2$-inch deep slots and a four-inch diameter hole at the bore was made of transparent Bakelite to a reduced scale for test at high speed.

After the disk was machined as shown in the sketch, figure 8, it was placed in the light field of the photoelastic polariscope, and pictures of stress taken with the disk rotating at high speed. Figure 9 is an isochromatic photograph of the stress distribution around the bore of the disk for rotation at a speed of 9,200 rpm. A comparison of stress values derived from this record with values obtained by standard methods[8] of calculations coincided closely. As shown in figure 10, the two curves are nearly coincident, and the linear variation from this condition is proportional to the square of the speeds $(9{,}200/9{,}000)^2$.

From the foregoing it may be definitely concluded that the present analytical theory applied to the calculation of stresses in such bodies as turbogenerator rotors gives a high degree of exactness.

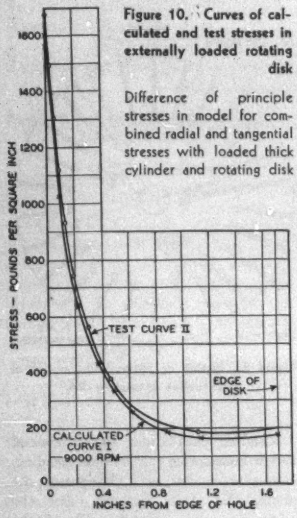

Figure 10. Curves of calculated and test stresses in externally loaded rotating disk

Difference of principle stresses in model for combined radial and tangential stresses with loaded thick cylinder and rotating disk

C. Lubrication Characteristics of Bearings

In addition to the vibration and stress investigations carried out in connection with the development of large 3,600-rpm generators, consideration was given to the various factors determining efficiency. As no promising features appeared for reduction in electrical and magnetic losses, the mechanical features such as windage and bearing friction were investigated. Generator designs based upon hydrogen as the cooling medium were developed. A machine of this kind ordered from the company with whom the writers are associated is shown in figure 11. This machine has explosion-proof yoke and end covers, oil-type shaft seals, and is designed for operating hydrogen pressures up to ten pounds per square inch. It has been in successful commercial operation as a hydrogen-filled machine for several months.

Assuming that hydrogen cooling reduces the generator windage losses to a minimum, bearing losses remain as a possible source for loss reduction. Tests on 43,750-kw 3,600-rpm and smaller machines indicated the possibility of further loss reduction by means of bearing design and lubrication control. For this reason investigations were made of the usual factors of lubrication such as the diameter, length, clearance, and pressure for the journal bearings, and the volume, temperature, and viscosity characteristics of the lubricants. The bearing losses were determined from the heat transfer to the lubricating fluid during circulation through the bearing. The losses due to heat radiation and convection were found small enough to be

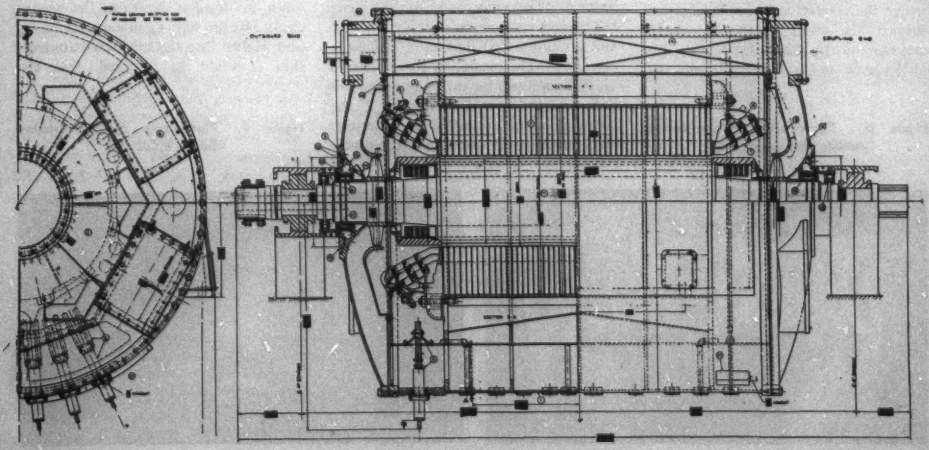

Figure 11. Hydrogen-cooled generator, 3,600 rpm, 60 cycles

neglected for comparative purposes.

The generators were driven by a direct-coupled test motor, and test conditions were varied by adjusting speed, oil flow, and oil cooler temperatures. Test data were obtained by readings taken at intervals. In most cases readings were not made until they remained constant for at least 15 minutes. The bearing kilowatt losses were calculated from the test data using density, specific heat values, and viscosities obtained from the oil distributors and checked in the laboratory.

The results of this series of tests may be summarized in the following statements:

It was observed that heat loss was proportional to the volume of oil supplied to the bearings. The curves in figure 12 compare the gallons of oil flow per minute against kilowatt losses for 12-inch by 12-inch bearings, and $13^1/_2$-inch by $13^1/_2$-inch bearings. The points *A* on the curves indicate the normal operating oil flows for the bearings. Points *C* are located to mark the calculated side leakage[9] quantities. The recommended oil flow is arbitrarily set at $2^1/_2$ times the side leakage, points *B*, for safe and efficient operation. Thus excessive quantities of oil forced to flow through the bearings produced high losses which would be considered unnecessary for normal operation.

It was also observed that the bearing losses were in proportion to the average oil temperatures. For all volumes of oil flow, with higher oil-supply temperatures minimum losses were obtained. The curves in figure 13 show a comparison of the losses measured for various quantities of oil flow at two inlet temperatures. Thus for the 12-inch by 12-inch bearing tests above, the kilowatt losses were reduced from 65 to 36 by adjustment of the oil temperature and the quantity of oil flow.

The physical dimensions and other data necessary for the theoretical calculations of power losses in the journal bearings are given in table I.

The calculated kilowatt bearing losses

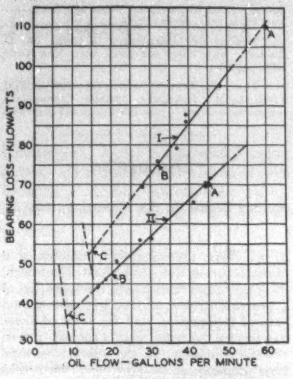

Figure 12. Test curves for bearing loss as a function of oil flow

For 3,600-rpm turbogenerators

Curve I—$13^1/_2$-inch by $13^1/_2$-inch bearing
Curve II—12-inch by 12-inch bearing

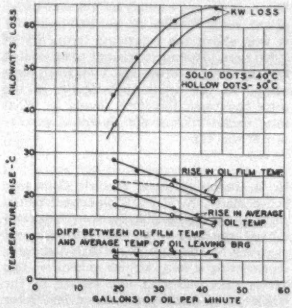
KILOWATTS LOSS
KW LOSS
SOLID DOTS-40°C
HOLLOW DOTS-50°C
TEMPERATURE RISE-°C
RISE IN OIL FILM TEMP
RISE IN AVERAGE OIL TEMP
DIFF BETWEEN OIL FILM TEMP AND AVERAGE TEMP OF OIL LEAVING BRG
GALLONS OF OIL PER MINUTE

Figure 13. Test curves for bearing loss and temperature rise as a function of oil flow for two inlet temperatures

for the 12-inch by 12-inch bearing, considering only the active portion in the lower half (except for the Petroff equation), are shown in figure 14, for methods by Karelitz,[9] Bradford and Eaton,[10] and Petroff[11], as a function of

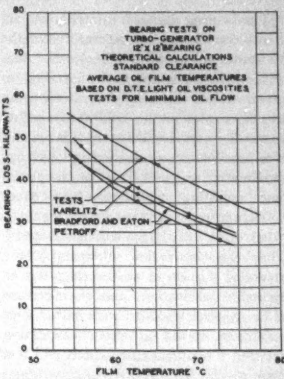

Figure 14. Theoretical calculations and test data for bearing losses with variable oil-film temperatures

average oil-film temperature. Several test points for this bearing with low quantities of oil flow are plotted. From these data it would appear that the measured losses are approximately 25 per cent higher than those calculated by the Karelitz or Bradford and Eaton methods.

Recent tests by Tichvinsky[12] on a 7-by $10^1/_2$-inch bearing at 3,600 rpm would indicate losses identical to those measured above, for a 12-inch by 12-inch bearing at a film temperature of 60 degrees centigrade. However, at 75 degrees centigrade the measured losses were 13 per cent lower than those which would be predicted by Tichvinsky's tests.

As a result of these tests, the following conditions have been established for the efficient operation of large high-speed bearings:

The oil flow to the bearing should be restricted to a safe minimum. An adequate amount is $2^1/_2$ times the side leakage calculated for the bearing. The top half of the bearing is relieved to allow this flow with the least possible pressure resistance and the bearing is designed with additional side relief to maintain an increased oil reserve. The oil supply to the bearing is metered through an orifice from a high pressure oil line, and quantity rather than pressure is the control criterion.

The oil outlet temperature should be maintained between 63 degrees centigrade and 70 degrees centigrade corresponding to thermocouple temperatures in the babbitt between 70 degrees centigrade and 77 degrees centigrade. The higher oil temperature is obtained by reducing the water flow in the oil cooler.

Table I. Bearing Dimensions and Data

Bearing (inches)	$13^1/_2$ by $13^1/_2$	12 by 12
Diameter of journal	13.478	11.980
Diameter of bearing	13.500	12.000
Nominal clearance	0.022	0.020
Nominal length	13.5	12
Effective length (inches)	11.75	10.5
Bearing load (pounds)	25,800	16,400
Bearing pressure (projected) (pounds per square inch)	162.5	130
Speed (revolutions per minute)	3,600	3,600
Bearing angle (deg)	90	90
Nominal oil required (gallons per minute)	60	46
Calculated end leakage (gallons per minute)	13.8	8
Adequate oil supply (gallons per minute)	31.5	20
Nominal bearing babbitt temperature (deg C)	60 (140 deg F)	60
Suggested bearing babbitt temperature (deg C)	77 (170 deg F)	77
Calculated minimum oil-film thickness, 77 deg C (inches)	0.003	.003

The bearing design must take into account the increased temperatures in the allowance of clearance dimensions. Adequate safeguards are to be installed to preserve the oil supply, controlled by thermocouples in the babbitt connected to auxiliary service lines. In this manner it is possible to reduce bearing losses approximately one-half based on the prevalent operating conditions (and effect a 0.3 per cent increase in efficiency at rated load for large turbogenerators). Thus the elimination of losses in the unloaded portion of the bearings due to excessive lubrication, and the decrease in the general viscosity with higher temperatures obtain a closer correlation between theoretical calculations and test data.

Summary

The preceding paper indicates:

1. The practicability of analytically predetermined critical speeds of rotors with cross sections having different moments of inertia at right angles.

2. The value of the photoelastic method for stress determination in rotating bodies.

3. The possibility of increased machine efficiencies by control of bearing lubrication.

As a résumé of the tests and calculations described, it is believed that in the recent development of large machines, efficient and strong structures have been realized and the door opened for the design of larger and more efficient generators.

References

1. MECHANICAL VIBRATIONS (a book), J. P. den Hartog. McGraw-Hill Book Company, Inc., New York, 1934, pages 174–8.

2. VIBRATION PROBLEMS IN ENGINEERING (a book), S. Timoshenko. D. Van Nostrand Company, Inc., New York, 1928, pages 62–6.

3. See reference 2, pages 333–6.

4. See reference 2, pages 328–30.

5. For description of equipment see PHOTOELASTIC ANALYSIS OF T-TAIL STRESSES, James J. Ryan. *Journal* of the Franklin Institute, volume 223, number 6, June 1937, pages 715–30.

6. FATIGUE OF SHAFTS AT FITTED MEMBERS, WITH A RELATED PHOTOELASTIC ANALYSIS, R. E. Peterson and A. M. Wahl. *Journal of Applied Mechanics*, A.S.M.E. *Transactions*, volume 2, number 1, March 1935, pages *A*-6, *A*-10.

7. PHOTO-ELASTICITY (a book), E. G. Coker and L. N. G. Filon. Cambridge University Press, Cambridge, England, 1931.

Also, A MANUAL ON PHOTOELASTICITY FOR ENGINEERS (a book), L. N. G. Filon. Cambridge University Press, 1935.

8. THEORY OF ELASTICITY (a book), S. Timoshenko. McGraw-Hill Book Company, Inc., New York, 1934, pages 55–7; 66–9.

9. PERFORMANCE OF OIL RING BEARINGS, G. B. Karelitz. A.S.M.E. *Transactions*, *APM*, 52–5, 1930, pages 57–70.

10. MACHINE DESIGN (a book), Bradford and Eaton. Third edition, John Wiley and Sons, Inc., New York, 1934, pages 123–48.

11. THEORY OF LUBRICATION (a book), M. D. Hersey. John Wiley and Sons, Inc., New York, 1936, page 38.

12. TESTS OF A 7- BY 10½-INCH BEARING AT 3,600, RPM, L. M. Tichvinsky. ASME *Transactions*, volume 60, number 5, July 1938, page 395 (figure 6).

Discussion

Sterling Beckwith: See discussion, page 34.

B. A. Rose (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The paper discusses the vibration of a generator rotor at the first and second natural frequencies, and for each of these frequencies the nodal points (points of zero vibratory motion) of the vibrations were very probably at or very near the center of the bearings or at certain spots in the pedestal structures themselves. We have found that a higher mode of vibration can exist such that the nodal points are located very close to the ends of the rotor body. The frequency at which resonance will occur is quite high, being of the order of 7,200 cycles per minute. This mode of vibration is not excited by the unbalance of the rotor because its natural frequency is well above the rotational frequency of 3,600 rpm. However, it is apt to be excited by the double-frequency vibratory force caused by the nonuniform rigidity of the rotor body and, therefore, should be taken into consideration in the design of generators of this type.

H. D. Taylor (General Electric Company, Schenectady, N. Y.): With regard to the three-to-one relationship between the second critical speed and the first critical speed observed by the authors on their test rotor representing a long turbine generator, this agrees quite well with data secured by the writer on a somewhat heavier test rotor weighing about 5,300 pounds. Calculated and test values of critical speeds for this rotor, when running with exceptionally rigid bearing supports, were as follows:

Critical Speed		Test	
	Calculated	Vertical	Horizontal
First	1,200	1,200	1,125
Second	4,000	3,900	3,250

It may be noted that the criticals in the vertical plane checked with calculations very closely, but that in the horizontal plane the first critical was reduced about 6 per cent, and the second about 17 per cent, due to slight horizontal flexibility.

We have also had experience with light rotors weighing up to 600 or 800 pounds, which showed little or no reduction of critical speeds below calculated values. It is common experience that for the heavy rotors of full-size turbine generators, the first critical is reduced considerably, as much as 20 or 30 per cent below the value calculated for rigid bearings, especially in the horizontal plane. Although supporting data are meager, the writer ventures the opinion that such machines also have a second critical speed reduced a great deal more from the calculated value, so that the ratio of the second critical to the first may actually be, instead of three to one, only two to 1, or even less.

However, there seems to be nothing particularly dangerous about the second critical speed. Tests with the 5,300-pound rotor demonstrated that the amount of vibration experienced at the first critical is a direct function of the amount of "static" unbalance in the rotor, and is not influenced by "dynamic" unbalance or "couples"; likewise, that the second critical responds only to couples, and is independent of static unbalance. A rotor having good static balance runs smoothly at the first critical; and with good dynamic balance, at the second critical also. In other words, good balance practically eliminates these critical speeds.

If a critical speed of 900 rpm is considered for a long generator field, the writer would anticipate the possibility of having a third critical speed within the running range, depressed from a higher calculated value by bearing flexibility. Also the possibilities for other types of vibration such as "whipping," would be greatly multiplied. However, I share the authors' view that lower critical speeds than 1,800 rpm will eventually be found practicable.

S. H. Mortensen and J. J. Ryan: It is assumed that the higher mode of vibration referred to by B. A. Rose is the third critical speed for turbogenerators. The deflection curve for this critical condition has nodes near the ends of the rotor body and at the bearing pedestals. A two-pole rotor with variable moment of inertia would probably set up double-frequency vibrations at one-half the third critical speed.

For a first critical speed of 1,600 rpm, a second of 5,000, and an assumed third of 10,000, the speed necessary to exhibit this type of vibration would be 5,000 rpm for a standard 3,600-rpm turbogenerator.

Such vibration phenomena has not been observed in the operation of these machines, but it is possible, under certain circumstances, this critical condition may be very close to the operating speed.

For the two-pole slotted rotor discussed in the paper it was observed that a double-frequency vibration occurred as the second critical speed was approached. The Geiger vibrograph showed approximately 0.0015 inches total motion at 6,600 vibrations per minute superimposed upon the single-revolution-per-minute frequency of 3,300 vibrations per minute for the maximum recorded motion of 0.003 inch. Since the double frequency disappeared at the second critical speed, it was not considered further.

However, the interesting discussion of H. D. Taylor stimulated the urge to further investigate the effect of the third critical speed, and the slotted rotor shaft was again operated on the test floor. As the second critical speed was approached the phenomena was repeated as above. Calculation of the third critical speed is thus a necessary factor in design to avoid double-frequency resonance of the nonsymmetrical rotor.

Turbine-Electric Textile-Range Drives

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NONMEMBER AIEE

A TEXTILE RANGE—the definition is offered for the benefit of those who may be unfamiliar with textile parlance—consists of a group of coordinated machines through which a continuous band of cloth is passed in rope or flat form (figure 1). Carrying on, in a group, the maximum number of operations of a textile finishing process which manufacturing conditions will permit lowers the cost of production by reducing the time and labor costs, and improved methods of driving such ranges

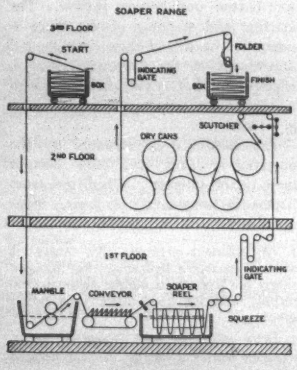

Figure 1. Group of related machines known as a soaper range

may lead to still further increases in the production rate per unit of equipment, with attendant reduction in unit cost of production.

As an example of this, we have observed mills in which the cloth was subjected to two successive drying processes, perhaps with an intermediate sizing operation. The cloth was passed through a range and either batched on a roll or folded into a box, after which it was passed through a second range consisting of a starch mangle and dry cans.

Early textile mills were driven entirely by mechanical means, usually by a combination of hydro and steam-engine power. As a textile range almost always included a drying process, the use of steam engines for driving them became general.

It may be noted at this point that ranges are frequently built for processing a wide variety of textures and weights of fabric. Therefore, a range of operating speeds as great as three or four to one is required. In addition, a threading or adjusting speed of perhaps ten per cent of the maximum operating speed for short periods is sometimes desired.

Based on these considerations, engine drive had two important advantages, and some of these drives are still in use.

1. Exhaust steam from the engine was used in the drying process, allowing the driving power to be obtained as a by-product.

2. Throttle control of the engine provided a flexible and inexpensive means of obtaining the desired range of speeds.

It had also, certain notable disadvantages.

1. Losses and maintenance costs resulting from complicated mechanical means of interconnecting sections of the range.

2. Inaccurate speed relation of sections due to belt slippages and nonuniform stretch of different fabrics processed on the same range.

The development of electric equipment and its general substitution for mechanical drive in textile mills led to consideration of electric drive for ranges. Earlier drives of the single-motor type retained some of the disadvantages noted in connection with engine drives. Later drives have been of the multiple-motor type, with basic speed control applied to the motor driving the lead section and motors driving follower sections held in step with the lead motor by compensating gate control. Such drives have been of the variable-voltage d-c type or variable-speed a-c type and have overcome many of the disadvantages common to single-motor and engine drives. It has also been possible to increase the number of sections comprising a range and to locate these sections on as many as three floors of a building when manufacturing reasons dictated the wisdom of such procedure.

Multiple-motor drives have provided an adequate solution of range problems in finishing plants where the efficient use of steam was already effected by the generation of power by turbine generators in a power station, with a low-pressure steam main carried into the mill to meet the demands for process steam.

For plants in which power is not being generated, even though there is a demand for low-pressure steam, the turbine-electric range drive offers interesting possibilities. This drive, in its usual form, consists of a gear-turbine flexibly coupled to a slow-speed a-c generator which has a shaft extension providing some form of mechanical drive for a section of the range then designated as the lead section. The generator is electrically connected to a-c motors, ordinarily of the induction type, which individually or in closely related groups drive other sections of the range (figure 2). Although a new arrangement, the components of this drive are standard pieces of equipment in simple form.

Basic speed adjustment is accomplished by varying the speed of the turbine either by hand or by remote throttle control or by the more expensive means of variable-speed governor control. The turbine satisfies the need for flexibility of speed control, and at the same time its use results in a low operating cost by providing the power needed for driving the range as a by-product from steam required to meet process demands. The fuel cost to supply the heat converted to

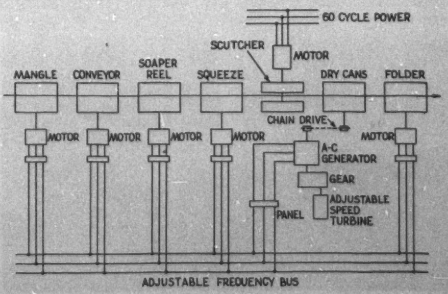

Figure 2. Schematic diagram of turbine-electric drive for a soaper range

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Figure 3. Motor drive to folder. Part of turbine-electric textile range drive in New England mill

Figure 4. Steam-pressure-regulating and control valve of turbine-electric range drive in New England mill

Figure 5. Turbine generator set, showing mechanical drive to dry cans and centrifugal field-control switch

power in the turbine is usually the equivalent of an electric-power cost of approximately one mill per kilowatt-hour.

With this form of drive, a section can be selected as the lead section on the basis of consideration of space and the convenient location of the prime mover. As this section is driven mechanically, its speed varies in direct proportion to that of the turbine.

The a-c generator, being driven by the turbine, generates a frequency directly proportional to the speed of the turbine and of the lead section. Motors driving other sections and having this generator as their power source are then driven at speeds having a uniform relation to the frequency of their power source except for the effect of motor slip due to load changes.

This effect of motor slip is advantageous because it allows motors to be initially placed in a fixed speed relation to the sections which they drive and yet provide ample flexibility, through a slight amount of belt action between sections, to accomodate the variable stretch factor of different grades of cloth. Special consideration is given to the slip factor and torque characteristics of motors for this application, the amount depending on local conditions to be met.

About a year ago a large New England mill installed a drive of this type which involved many interesting problems related largely to control.

In this case, the dry cans were mechanically driven. As it was desired to warm up the dry cans in motion and to wash them on shut down, with the balance of the range stationary, simple switches were provided to disconnect the follower motors from the generator. This required a range of operating speeds from full speed to one-third speed, but did not demand low speed for threading or adjustment, a fact which somewhat simplified the control problem.

The operator is concerned only with a four-button push-button station. The starting and stopping of the range is controlled by two of these buttons, and adjustment of the operating speed is effected by the other two buttons through a pilot-motor adjustment of valve or governor.

The control cycle initiated by the operation of "start" and "stop" buttons may be of interest. When the start button is pressed, the following steps take place:

1. A solenoid-operated pilot valve is opened, causing a hydraulic relay to open slowly a valve which admits steam to the turbine, allowing acceleration to a preset speed.

2. The generator field circuit is closed, allowing electrical energy to be generated as soon as rotation starts.

3. The generator field rheostat is short-circuited, thereby applying full field to the generator in order to allow the follower motors to develop maximum torque at very low frequency.

Figure 6. General view of turbine generator set with chain drive to dry cans

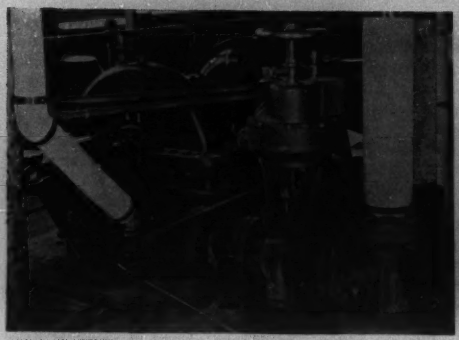

Figure 7. Motor-operated control valve for turbine-electric range drive in New England mill

Figure 8. Motor-driven cloth conveyor

4. A timing relay is started which, after a generator frequency sufficient to supply adequate motor torque is reached, breaks the short circuit across the generator field rheostat and thereby reduces the field current to a normal value.

When the stop button is pressed, the following operations occur:

1. The solenoid-operated pilot valve is closed, causing the hydraulic relay to close a valve interrupting the steam supply to the turbine.

2. A magnetic switch is closed. This connects a three-phase resistor across the generator terminals, supplying braking effect for rapid deceleration.

The generator field circuit remains closed until the generator comes to rest, when the field circuit is opened by a centrifugal relay driven by the generator.

Each follower-motor circuit contains a thermal overload relay. The contacts of all these relays are connected in series with the stop button circuit, so that excessive load on any motor will shut down the entire range.

It should be understood that when this type of drive is started, the mechanically driven section starts with the turbine, at which time the voltage and frequency at the generator terminals is at zero.

Carefully conducted tests indicate that follower motors start when the generator frequency reaches a value somewhere between two and three cycles and that there is a time lag of about $1^1/_2$ seconds between the starting of the turbine and the starting of the follower motors.

For this reason it has been found desirable to provide floating rolls, capable of accommodating about three feet of cloth, between the mechanically driven

Figure 10. Main control panel for generator and braking resistor

Figure 9. Motor-driven soaper reel. Part of turbine-electric range drive in New England mill

Figure 11. Motor-driven soaper reel

A High-Gain D-C Amplifier for Bio-electric Recording

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Synopsis: This paper describes a d-c amplifier for use with the cathode-ray oscillograph whose maximum voltage amplification is 6×10^6. This amplification is attained with a noise level referred to the input of less than two microvolts over a 5,000-cycle-per-second band, and without the drift due to variations in battery voltages and circuit constants characteristic of such amplifiers. The amplifier is push-pull throughout and provides a choice of two input circuits. Voltage sources in which both terminals are at a high impedance to ground are connected grid-to-grid, symmetrically to ground, while sources in which one terminal is at ground potential are connected to either grid and ground, the first stage, in this case, acting as a phase inverter. Stability and phase inversion are obtained by means of a circuit that makes the output relatively independent of battery voltage and tube-constant variation. The amplifier is simple and rugged, uses ordinary radio-type tubes which do not have to be carefully matched, is constructed of ordinary radio-type components, and has reasonable battery requirements.

THE PROBLEM of recording the potential-time variations produced by bio-electric phenomena is a difficult one. The maximum potential differences occurring in various biologic preparations range from 10^{-4} to 10^{-1} volts. The potential-time variations themselves range from unidirectional and very low-frequency recurrent types (figure 5) to phenomena whose period is less than a millisecond. The string galvanometer has been used for such work in the past and still has wide acceptance. Its ability to record d-c phenomena and its high sensitivity under proper conditions, 10^{-4} volts per millimeter, make it almost ideal for this work. Recently, sensitivities of the order of 10^{-6} volts per millimeter have been obtained by using low-gain low-noise-level amplifiers with the string galvanometer. Opposed to the advantages of this instrument, however, are its poor frequency response (0–250 cycles per second), its variation in sensitivity with temperature, the fragility of the quartz string in the galvanometer, and its low input impedance when used without an amplifier.

The cathode-ray tube, on the other hand, has none of these disadvantages and with present day tubes and high-speed films, the recording of nonrecurrent biologic phenomena is not difficult even with moderate anode voltages. The cathode-ray tube is inferior to the string galvanometer only in its sensitivity, three volts per millimeter, for a representative three-inch tube with 1,000 volts on its anode. While the string galvanometer, whose sensitivity is 30,000 times as great, can record bioelectric potential differences directly, the cathode-ray tube must be associated with an amplifier to accomplish the same result. In order to obtain a sensitivity of 10^{-6} volts per millimeter, to make use of the high-frequency response of the cathode-ray tube, to be able to reproduce faithfully d-c phenomena, and to have sufficiently low noise level to justify the high sensitivity, one must associate with the cathode-ray tube a d-c amplifier responding to a band width of 0–10,000 cycles per second which has a maximum voltage amplification of 3×10^6, and a noise level, referred to the input, of less than two microvolts over a 5,000-cycle-per-second band.

Such performance requirements, while desirable in an instrument for laboratory research, need not be as severe in special applications such as human electrocardiography as an example. The human heart beats from 70 to 80 times per minute in a normal person, and an amplifier which responds down to one cycle per second will faithfully reproduce the action potential produced by the heart once during each beat. One can construct resistance-capacitance coupled amplifiers that will do this without great difficulty, and such amplifiers are generally used for this work. One could not, however, practically construct such an amplifier to reproduce faithfully phenomena such as presented in figure 5. Such an amplifier would have to have a time constant in the neighborhood of 150 seconds and the coupling capacitors required would be enormous. Since even lower-frequency phenomena occur, the d-c amplifier is seen to be the type that must be used.

If the cathode-ray tube is to be used for this work, therefore, an amplifier must be constructed fulfilling the requirements already stated. The most difficult problem to be solved in the design of such an amplifier is the one of compensating for the "drift" in the operating voltages of the output stage due to small variations in operating voltages and tube constants in the input stage. This problem becomes an increasingly difficult one to solve as the voltage amplification is increased, since the maximum uncompensated residue of the variations in the input stage that can be tolerated becomes smaller and smaller. The amplifier described in this paper solves this difficulty and attains a maximum voltage amplification of 6×10^6, sufficient for a sensitivity of 5×10^{-7} volts per millimeter with a three-inch cathode-ray tube operated with 1,000 volts anode potential. The amplifier is compact, easy to operate and adjust, and inexpensive to construct. Only moderate battery voltages are required and the current drain is very low. It has been found that low noise level and high stability may be attained even with the use of ordinary radio-receiver-type circuit components.

Design and Theory

Noise Level

The 38-type tube, a power output pentode, when operated at very low plate and screen voltages, is a practical amplifier tube possessing very low inherent noise. The noise voltage output of a single amplifier stage using this tube operated as stated, is equivalent to a noise voltage of less than two microvolts impressed on the grid of the stage, pro-

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section and the motor-driven sections.

Experience has shown that, after essential adjustments have been made, this type of drive can be easily and successfully operated by the ordinary finishing-plant operator.

The use of a-c motors simplifies wiring installation and reduces the maintenance expense to a minimum.

Smooth acceleration and deceleration of the turbine-electric drive combined with accurate speed control reduces damage to the fabrics in process, resulting in maximum production.

vided the stage passes no frequencies higher than 5,000 cycles per second. The high emission of the power-type tube makes this tube practicable as a voltage amplifier even at plate voltages and screen voltages of 12 volts and lower. Four such tubes, two per stage, are used in the first two stages.

Amplification

The remainder of the desired voltage amplification is obtained with two additional stages. Four type 6J7G tubes are used, two to a stage. These are radio-type pentodes of the sharp-cutoff variety. They provide a voltage amplification of about 130 per stage. A plate-supply voltage of 225 volts on the output stage provides for an undistorted voltage output sufficient to cover the cathode-ray screen.

Stabilization

There are two methods, in general, for overcoming the "drift" in operating voltages due to slow variations in battery voltages and tube constants. One method is to provide an automatic means for compensating for such drift; the other, is to make the circuit operating voltages relatively independent of such changes without at the same time destroying the amplifying properties of the circuit. Several circuits have been proposed in the literature for use with the "electrometer" tube in single-stage amplifier circuits. These operate according to the first method. The employment of such means in a multistage amplifier would complicate the operation and adjustment to the extreme.

The second method of attack is more practical for a multistage amplifier and has several advantages. A circuit whose operating voltages are relatively independent of battery voltage and tube-constant variations will be relatively simple to adjust and maintain. The replacement of tubes and aging of batteries will have little effect on amplifier adjustment and performance. Furthermore, there is no necessity for a knowledge of the exact characteristics of each tube to be used in the amplifier as is often necessary in compensation schemes.

The use of push-pull circuits is immediately suggested as a possible means of rendering the steady-state output voltage of the amplifier independent of tube and battery variations. With perfectly matched tubes, any variations in the output due to variations in supply voltages will cancel. Furthermore, the tubes may easily be self-biased without affecting the amplifying properties of the circuit. Such a circuit, however, would not suffice to keep the operating voltages of the output stage at optimum values should excessive changes develop in the batteries supplying the first stages or should matched pairs of tubes be replaced by other matched pairs of somewhat different characteristics. In addition, some provision for phase-inversion would be necessary for use with voltages in which one terminal is grounded unless one would be willing to use only one side of the amplifier for signal voltages.

Even if one decides, however, that the last mentioned difficulties are not too important, there remains the fact that in a practical sense, commercial-type tubes cannot be perfectly matched. A push-pull circuit using unmatched tubes will not completely cancel variations in output voltages due to drift but will only partially cancel them, and for that reason the push-pull circuit must be used with additional modifications to take care of the uncancelled residue.

The fact that unmatched tubes must be used brings about still another difficulty. It is desirable to maintain balanced push-pull voltages in all stages ($E_1 = -E_2$ in the arrow directions, figure 2). It will be generally impossible to do this in a simple push-pull circuit that uses unmatched tubes without some circuit modifications. While this balanced condition is not too important in a low-gain amplifier, it becomes increasingly important as the voltage amplification is increased.

The circuit finally used in the amplifier is a modified push-pull circuit in which phase inversion is an inherent property, balanced push-pull voltages are automatically maintained despite tube differences and circuit unbalances, optimum operating voltages are maintained in all stages even under large variations of

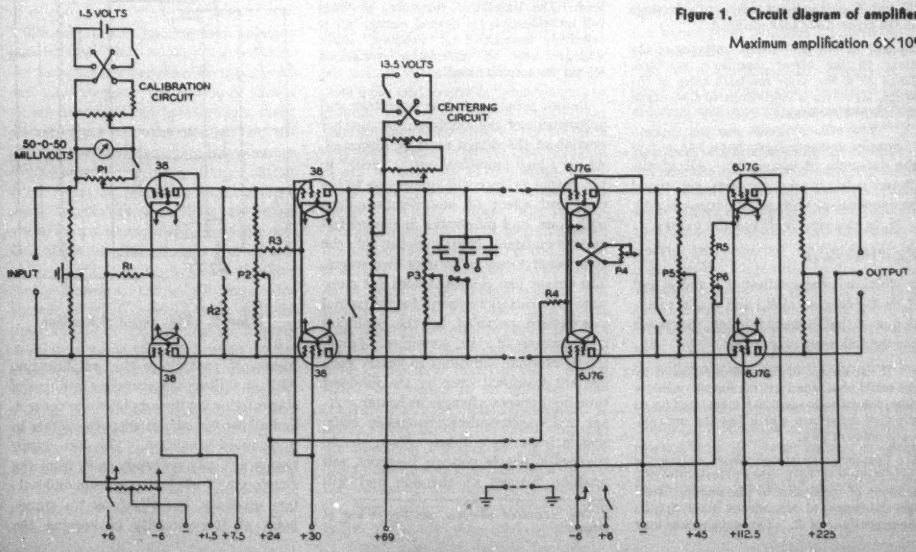

Figure 1. Circuit diagram of amplifier

Maximum amplification 6×10^4

supply voltages and despite tube replacements, and the "drift" due to the previously mentioned uncancelled residue may be made as small as desired. The basic circuit that accomplishes these results will now be discussed.

The Basic Circuit of the Amplifier (Figure 2)

The circuit characteristics set forth in the following discussion depend on calculations which assume operation over the linear portion of the tube characteristics. Such calculations are valid since the amplifier is actually operated over the essentially linear portion of the tube characteristics. The discussion is valid not only for pentodes, the tubes used, but holds equally well for tetrodes and triodes. The calculations upon which the discussion is based are more complex in the case of tetrodes and pentodes than they are in the case of triodes.

The following symbols will be used:

R_0 is the plate load resistor and has the same value on each side of the amplifier stage.

R_p is the dynamic plate resistance of the tube. The subscripts (1, 2) refer to tubes $VT1$ and $VT2$ and indicate that the tube constants may differ for different tubes.

R_{ps} is the static plate resistance of the tube at a given operating point and is the ratio of static plate voltage to static plate current.

μ is the amplification factor of the tube at the operating voltages used. The subscripts have the meaning already given.

R is the common cathode resistor.

E_1 and E_2 are the input voltages to the stage in the arrow directions specified.

E_3 and E_4 are the output voltages of the stage in the arrow directions specified. Since R_0 is the same for both sides of the stage, $E_3 = -E_4$ is equivalent to $I_1 = -I_2$ in the arrow directions.

Supply voltages have been left out in the interests of simplicity. All of the above voltages and currents are signal components of voltage and current only.

If, in this circuit, R has the value

$$R \geqq 10(R_0 + R_p)/\mu$$

in which μ is the smallest of μ_1 and μ_2 and R_p is the largest of R_{p1} and R_{p2}, a condition on R that is easily fulfilled, the circuit has the following properties:

1. If the circuit of figure 2 is replaced by the usual equivalent circuit for the vacuum tube, the cathode resistor R is replaced by an effective resistance which has the approximate value of $2R_p$.

2. The property stated above makes the plate current of both tubes practically independent of variations in plate-supply voltage, the degree of dependence depending on the magnitude of R. This dependence may be made arbitrarily small, within practical limits, by making R arbitrarily large.

3. The property of "1" also renders the plate current of both tubes independent of variations in the dynamic plate resistance of the tubes. This property renders the operating voltages of the circuit independent of tube aging and tube replacement.

4. A single-ended input voltage E_1, $E_2 = 0$, applied to one side of the amplifier stage will produce essentially balanced, push-pull output voltages. The total output voltage, $E_3 - E_4$, will be the same as that produced by an input voltage, $(E_1' - E_2')$, applied from grid-to-grid, where $(E_1' - E_2')$ is equal to the voltage E_1 applied from one grid to ground.

This feature is the phase-inverting property of the circuit and has already been discussed for triodes by Goldberg.[2] This phase-inverting property of the circuit enables the amplifier to produce the same output voltage for a given input voltage irrespective of the manner in which the input voltage is applied to the input circuit of the amplifier.

5. Essentially balanced, push-pull output voltages are produced by the stage regardless of unbalances in input voltages, or differences in the characteristics of the component tubes. (A calculation made for a typical circuit to which balanced, push-pull input voltages are applied but in which the plate resistances of the component tubes differ by 10 per cent shows that the output voltages differ by only 0.1 per cent when $R = 7(R_0 + R_p)/\mu$, a value of R less than that recommended.)

6. The final and one of the most important properties of the circuit is that amplification of balanced push-pull voltages is not affected by the introduction of the cathode resistor, R, since the plate and screen currents due to such voltages cancel in the common cathode lead. The amplifier, therefore, provides full amplification for desired signals but is relatively insensitive to "in-phase" input voltages and to undesirable variations within the amplifier itself.

Before going on to the operation and adjustment of the amplifier, yet another portion of the design must be discussed. At very high amplifications, a "drift" in the output voltage will appear due to the combined effect of heater-voltage-drop with time, and differences in the heater-voltage-emission characteristics of the component tubes in the first two stages. The circuit just discussed does not minimize such variations except for the partial cancellation provided by the push-pull construction of the amplifier. Small, quick, random variations in heater voltage are smoothed over by the inherent time lag between changes in heater voltage and corresponding changes in emission in heater-type tubes. Slow, steady changes in heater voltage, however, will produce changes in emission and will cause drift if the emission changes are different in the tube components of each of the first two stages of the amplifier. This effect may be reduced to a negligible quantity by providing a portion of the grid and screen voltages of the first two stages from the heater-voltage supply in such a way that any change in the heater voltage, will change the emission and the grid and screen voltages in such an antagonistic manner so as to keep the steady-state plate current constant. It has been found that an adjustment of the circuit that will do this for any one type 38 tube in the first two stages, will do it sufficiently well for any other type 38 tube that may be used to replace the original so as to keep the drift due to this cause within a tolerable minimum at maximum amplification. The paper will now discuss the operation and adjustment of the amplifier.

2. For numbered reference, see list at end of paper.

Operation and Adjustment

It is desirable from the standpoint of the proper operation of the amplifier to provide a means of adjusting the static operating voltages in each stage differentially, so that the static plate-to-plate voltage of each stage may be adjusted to zero or very nearly to zero. Such an adjustment provides for the maximum of stability in the amplifier, provides a

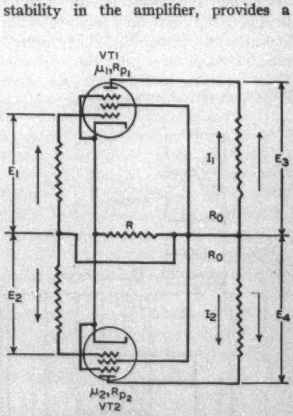

Figure 2. Basic circuit of amplifier

means of controlling the amplification without shifting the operating voltages of stages following the amplification control, and allows the output stage to operate in a balanced condition. This last condition is not only necessary both from the standpoint of efficient operation and battery economy, but also from the standpoint of the necessity of keeping the

cathode-ray-tube spot near the center of the screen with zero input voltage to the amplifier. Since it is sometimes desirable to shift the zero input voltage position of the spot to various other positions on the screen, the static plate-to-plate voltage balancing control of some one stage may be used to unbalance the static output voltage of the amplifier sufficiently to move the spot to the desired position.

In addition to the balancing controls, and a means of varying the voltage amplification, there should be some method for controlling the width of the band of frequencies transmitted by the amplifier, at least at the higher amplifications, so that the inherent amplifier noise may be reduced to considerably less than a microvolt in those cases where the input voltage is very small and the reduction in band width is not objectionable. Finally, there should be some means for quickly and simply checking the condition of the static plate-to-plate voltage balance of each stage.

screen. This condition occurs only when the static plate-to-plate voltage of the third stage is zero, the condition of balance. Adjustment of the second stage is accomplished in a similar manner. The first stage balance is set with the aid of a voltmeter whenever tubes are replaced in that stage, and does not need readjustment as long as the same tubes are used. In normal use of the amplifier, the second stage is not adjusted to balance, the balancing circuit in this case acting as a centering device, coarse and fine controls being provided for ease in adjustment.

Circuit Description

The input to the amplifier, as illustrated in figure 1, is high-impedance grid-to-grid, the grid-leak resistors providing push-pull input to the first stage. An input that is unbalanced to ground may be connected from either grid to ground, the remaining grid being grounded in this

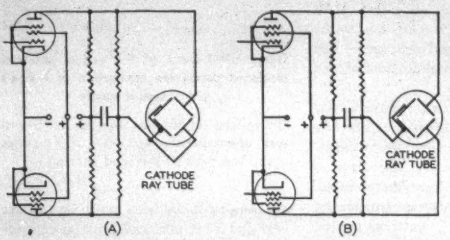

Figure 3. Suggested schemes for connecting the amplifier to ordinary cathode-ray tubes with internal connections between two plates and the anode

The scheme for checking such balances is as follows: Plate-to-plate short-circuiting switches are provided in the second and third stages. The closing of such a switch automatically balances the static plate-to-plate voltages applied to the grids of the following stage but does not affect the mean operating voltages of that stage unless the preceding stages are seriously unbalanced, a condition that does not exist in this amplifier unless some portion of the amplifier is defective. These balance indicating controls are provided for the second and third stages and not for the output stage since the static plate-to-plate voltage of the output stage is never more than a few volts (depending on the component tubes) and is not objectionable. The third stage is balanced by closing the second-stage plate-to-plate short-circuiting switch and adjusting the balance control in the third-stage plate circuit until alternate opening and closing of the third-stage plate-to-plate short-circuiting switch does not produce motion of the spot on the cathode-ray-tube case. As has been stated, the output voltage from the amplifier for a given input voltage is the same whether it be applied from grid to grid or from one grid to ground. For this reason, calibration voltages may be supplied by the injection of known direct voltages into the grid circuit of one tube of the input stage. These voltages may be varied from 2×10^{-4} to 5×10^{-3} volts. The 100,000-ohm potentiometer, P_3, is used to balance the static plate-to-plate voltage of the first stage. Since this control can adjust for a static plate-to-plate voltage not greater than one volt, the tubes in this stage must be matched to the extent that the IR drops in their plate load resistors differ by not more than one volt. Tubes which will match in an ordinary tube checker will meet this requirement in about 50 per cent of the cases, although the operating voltages in the amplifier differ considerably from the rated operating voltages of the tubes as provided by the tube checker. The voltage amplification of the first stage may be changed from 15 to 1.25 by shunting a 75,000-ohm resistor, R_3, figure 1, from plate to plate. This reduction makes the over-all gain of the amplifier about 500,000 maximum, as compared to 6,000,000 with the shunt removed. This lower range is desirable when the maximum available voltage amplification is not needed since the lower amplification of the first stage will

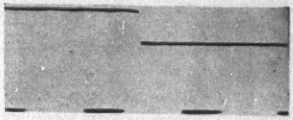

Figure 4. Response of amplifier to 100-microvolt calibration voltage applied by manually depressing calibrator key

The dashes are a portion of the timing record and represent 0.04-second intervals

minimize unbalances in the second stage due to d-c polarization voltages which may occur at the electrode contacts with the biologic specimen being studied.

Tube matching on a tube checker is sufficient for tubes in the second stage. The balance control, which is also the centering control, is also used to counteract any effect of steady input voltages brought about by electrode polarization, etc. This control circuit injects a continuously variable push-pull voltage into the second-stage plate circuit which may be reversed by means of the reversing switch. The one-megohm variable resistor, P_2, shunted between the plates of the second stage provides a continuously variable means of controlling the magnitude of the amplification. Reduction in band width is obtained by means of three different shunting capacitors across the control and are effective only when the gain control is near maximum.

There are two means for bringing about static balance in the third stage and these are of sufficient range so that unmatched tubes, taken at random from the dealer's shelves, may be used for this stage. A coarse means is provided by the six-ohm variable resistance, P_4, and a reversing switch, which provides a variable resistance in the heater circuit of either tube at will. This control cannot be used for fine adjustments because of the time lag in the heater-voltage-cathode-emission characteristic. It is used only when discharging batteries have brought about a marked drop in heater voltage or when tubes are replaced in the stage. Fine adjustment is accomplished with the 10,000-ohm potentiometer, P_5, in the plate circuit of the third stage.

Tubes matched in a tube checker are sufficiently alike in their characteristics so that they will work satisfactorily in the output stage. Balancing is unnecessary since the static output voltage is never more than a few volts with such tubes, and has a negligible effect on the position of the cathode-ray-tube spot.

Grid bias for the output stage is partially variable by means of the variable resistor, P_6, so that it may be adjusted to the optimum value under conditions of actual operation.

The output connections of the amplifier as shown in figure 1, are intended for a cathode-ray tube which has separate connections to all deflecting plates. The mid-terminal is connected to the anode, and the two outer connections to a pair of plates of the cathode-ray tube. Figure 3*A* and *B*, illustrate possible connection schemes which may be used with cathode-ray tubes possessing internal connections between two deflecting plates and the anode. The connection, *A*, makes use of only half of the output voltage of the amplifier, and for this reason, the plate-supply voltage of the output stage must be increased over that indicated in figure 1, so that half of the undistorted voltage output will be sufficient to give full deflection. The scheme, *B*, applies push-pull voltages to both sets of deflecting plates and results in a deflection proportional to 0.707 of the output voltage of the amplifier. The direction of deflection in this case is along a line making an angle of 45 degrees with the axis of either set of plates.

Constructional Details

The amplifier is built in two units to minimize the effects of stray coupling. The first unit, which is well shielded to prevent pickup, contains the first two stages of the amplifier and all of its associated batteries with the exception of the six-volt storage battery supplying the heater voltage. Small 22.5-volt *C* batteries are used to supply plate and screen voltages with a total drain of less than a milliampere. Tubes are packed in absorbent cotton, shielded, and mounted in suspension mounts by means of rubber bands for the purpose of minimizing microphonic disturbances. Shielded cables connect to the calibration key and to the unit containing the last two stages. The maximum voltage amplification of the first two stages is 350.

The last two stages, which have a voltage amplification of approximately 17,000, are housed in a small commercial-type amplifier chassis. Connections to batteries are by a multiconductor cable. Light-duty 45-volt batteries supply the 225 volts of plate-supply batteries needed for the last two stages. Circuit arrangements are such that the actual supply voltages to stages one to four are 22.5, 57, 67.5, and 225, a total of 372 volts, although the total plate battery supply is only 294 volts. Proper bias voltages are obtained for each stage, despite the large cathode resistors employed, by proper circuit design.

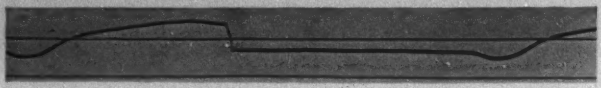

Figure 5. Record of one cycle of the injury action potential from the surface of a tortoise heart

The dashes represent 0.04-second intervals. The total elapsed time for each cycle is 4.3 seconds. This record illustrates one type of low-frequency phenomena handled by the amplifier

Performance

In actual operation, a warming-up period of about 15 minutes is required to secure stability at the higher amplifications. After the amplifier has reached steady-state conditions, minor adjustments to the static balance may be necessary but can be made in no more than a minute or two if necessary. During use, after initial adjustments have been made, only the amplification, centering, and calibration controls need be used.

The amplifier described has been in constant use for a year and a half and has given extremely satisfactory results. In all this time, there has been no necessity for battery or tube changes and the aging of the batteries used with the amplifier has in no way impaired its performance. The amplifier has proved itself to be very dependable and has justified its design in every way. That the performance of the amplifier is not fortuitous is demonstrated by the fact that another such amplifier has been built and been in use for the last year and it has performed just as dependably as the original.

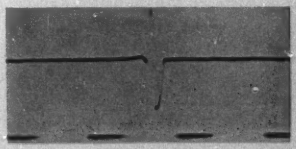

Figure 6. Record of the action potential produced during the contraction of a frog's gastrocnemius muscle

The voltage amplification used for this record was approximately 450,000. The dashes represent 0.04-second intervals

This paper, therefore, has described a d-c amplifier whose over-all voltage amplification is comparable to those obtained in resistance-capacitance-coupled amplifiers and is limited only by the unavoidable noise level of the tubes in the first stage.

References

1. The Measurement of Small Alternating Voltages at Audio Frequencies, E. A. Johnston and C. Neitzert. *Review of Scientific Instruments*, volume 5, 1934, pages 196–200.

2. Direct-Coupled Amplifiers, Harold Goldberg. Master's thesis, 1936, University of Wisconsin Library, Madison.

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Industrial Notes

Expansion Program for Power Company.—A $16,000,000 construction program, including a new 80,000-hp generating unit, will be inaugurated early in 1940 by the Duquesne Light Co., Pittsburgh. The steam turbine generator will be installed at the James H. Reed power station on Brunot Island and will increase the total generating capacity of the system to 752,000 horsepower. The cost of the turbine alone and its auxiliary equipment is expected to reach $5,000,000. The regular construction budget for the year 1940 includes other items such as extensions to substations, high voltage line extensions, additional distribution facilities, and increased transformer capacity throughout the system, the total cost of which will be several million dollars. An even larger amount will be expended in 1941 for the same class of work.

Heyer Company in New Plant.—The Heyer Products Co., Inc., manufacturers of battery charging and testing equipment, etc., has moved into its newly completed, larger plant located at 471–519 Cortlandt St., Belleville, N. J. The new structure is of the latest modern type and was designed to serve the specific needs of the company's manufacturing methods and processes.

New Offices for Line Material.—The executive and sales offices of the Line Material Company have been removed to 750 North 2nd St., Milwaukee, Wis.

Profit Sharing for G-E Employees.—Under the general profit sharing plan of the General Electric Company, approximately $2,400,000 of earnings was distributed to employees in 1939 compared with $557,000 for 1938. The employees also have received approximately $2,350,000 as a cost-of-living adjustment of their earnings for 1939, compared with $3,298,000 for 1938. Under these two plans, the total additions to regular earnings of eligible employees amounted to $4,750,000 for 1939, compared with $3,855,000 for 1938. In August the employees received a payment from earnings under the general profit sharing plan for the first six months this year, and in the latter part of December payment was made for the second six-months period. For eligible employees with five or more years of service, the payment for the last half of this year was equivalent to 3.75 per cent of their earnings, which, together with 2.0 per cent for cost-of-living adjustment, makes a total of 5.75 per cent added to their regular earnings for the last six months this year. The company now has about 67,000 employees, or 10,000 more than a year ago.

New Allis-Chalmers Plant.—Completion of what is described as the most modern distribution transformer plant was announced recently by the Allis-Chalmers Manufacturing Co., of Milwaukee. The new plant is an addition to the company's transformer factory at Pittsburgh, to be known as the River Plant of the Pittsburgh Works, and is said to be the only transformer plant that is laid out and set up for modern line production operation throughout. Raw materials start at one end, and at the other end the transformer comes off the line not only completed, but fully tested and boxed, ready for shipment.

Employees Share in Westinghouse Earnings.—Adjusted compensation of 10 per cent was paid to all employees of the Westinghouse Electric & Mfg. Co. in December, in accordance with the Westinghouse wage and salary plan. The amount of adjusted compensation is established each month in proportion to the net earnings of the preceding three months. In November the adjusted compensation to all Westinghouse employees was 6 per cent. Approximately 46,500 employees received the December extra compensation in the company's 57 manufacturing and service plants throughout the country, and in all sales and service offices.

Trade Literature

Cable Terminators.—Bulletin 65-2, 32 pp. Describes a complete line of cable terminators and potheads. Delta-Star Electric Co., 2400 Block Fulton St., Chicago, Ill.

Transformers.—Bulletin TU-1A, 8 pp. Describes new, rural line transformers; includes connection diagrams, information on the care and operation of rural-line transformers and other valuable data. Wagner Electric Co., 6400 Plymouth Ave., St. Louis, Mo.

Demand Meters.—Cat. Sec. 42-414, 24 pp. Describes indicating and recording demand meters for measuring block-interval kva-demand under all conditions of load and power factor. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Washers.—Stock List 55-C. Lists thousands of washer specifications in various materials, including steel, brass, copper, aluminum, fibre, etc., carried in actual inventory and available for immediate shipment. The Wrought Washer Mfg. Co., Milwaukee, Wis.

Circuit Breakers.—Bulletin 3911, 6 pp. Describes the electrical equipment of the new Inland Steel hot strip mill, with particular emphasis on the air circuit breakers and switchboards installed in this new plant. I-T-E Circuit Breaker Co., 19th & Hamilton Sts., Philadelphia, Pa.

Instruments.—Bulletin GEA-1758B, 12 pp. Describes a complete line of rectangular switchboard instruments. Includes a-c and d-c ammeters and voltmeters; a-c wattmeters, power-factor meters, frequency meters and special instruments. General Electric Co., Schenectady, N. Y.

Instruments.—Condensed Catalog E, 66 pp. Describes a comprehensive line of electrical measuring instruments for research, teaching and testing, and includes standards, galvanometers and dynamometers, bridges, potentiometers, photometric apparatus, miscellaneous apparatus, primary elements, accessories, supplies and instrument parts. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

Industrial Condensers.—Manual, 16 pp. Of practical value to designer, manufacturer or serviceman dealing with motor-starting capacitors. Several pages are devoted to pertinent information on motor-starting capacitors, followed by an alphabetical listing of standard motor brands and types, with their required capacitors listed by catalog number, capacity, a-c voltage, dimensions, construction, illustration and list price. Thus the correct replacement can be selected for any capacitor-start motor. Aerovox Corp., New Bedford, Mass.

New Motion Picture Catalog.—No. GES-402F, 20 pp. This booklet describes a large number of motion pictures now offered by the General Electric Co., Schenectady, N. Y., for the use of organized groups such as educational institutions, engineering societies, etc., for which no charge is made, with the exception of a small shipping cost. The new catalog lists the films under the classifications of science, generation and distribution of electricity, transportation, electric equipment, industry, light and lighting, welding, and household appliances. Listed in the catalog are 12 distribution points throughout the country.

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New Products

High Voltage Indicating Equipment.—This apparatus is applicable for use on lines up to 13 kv and is furnished with a two-range instrument with scales 0–7 and 0–14 kv, by Ferranti Electric, Inc., 30 Rockefeller Plaza, New York City. The indicator consists of a long, Bakelite tube, terminating at the live end with a metal spike. A metal collar on the outside of the tube forms the second plate of a condenser with the spike, the Bakelite tube acting as the dielectric. An electrostatic voltmeter, $2\frac{1}{2}$ inch dial, is connected in series with this condenser, one end of the instrument being terminated with a ground lead 6 feet long, with strong clip suitable for attaching to the nearest ground metal. The value of the condenser in series with the instrument is so chosen, in relation to the capacity of the instrument, that a comparatively low voltage instrument can be used. The actual voltage across the instrument is 600 volts at full scale reading. The chief use for the apparatus is in power stations and substations where it is necessary to know whether normally energized metal is dead before work on it is attempted. Its principal advantage over the usual type of neon lamp detector is that the exact voltage is shown.

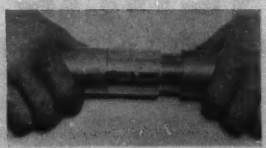
Underground Interconnecting Device.—The G&W Specialty Co., 7780 Dante Ave., Chicago, Ill., has added to its line of type "PD" combination oil and air break disconnecting switches a four-way, single-pole,

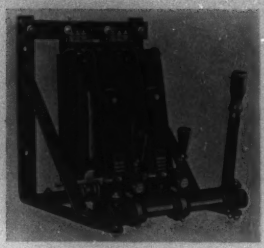
5,000-volt, 500-ampere interconnecting device for subway installation. The plug links are operated by a Bakelite insulated handle. Full load is broken under oil and the air break in series with the oil break insures complete safety. A Bakelite shield within the tank covers live parts and the handle, of similar material, is kept within the tank which is closed by a Resistoyl gasketed plate.

Improved Radio-Proof Insulator.—Having developed a special conducting glaze for the purpose, the Ohio Brass Company, Mansfield, O., is now producing a complete line of radio-proof pintype insulators in which this glaze is applied under the regular glaze at critical areas. Known as conduction-glazed Silentypes, these insulators supplement the company's line of metallized Silentypes. The underglaze is applied to

the conductor groove, the tie wire groove, the pin hole and the joints (of multiparts). After the conducting glaze is applied the insulator is coated with the regular outer glaze and then fired. The conducting element in the underglaze comes through the outer glaze during firing, making a good bond with the tie wire and conductor. Aside from offering good radio characteristics the manufacturer claims that the new conduction glaze results in a high degree of uniformity, provides a treatment which is permanent electrically and mechanically, prevents conductor abrasion by providing a smooth finish, and permits use of the time-tested standard pintype designs.

Bus Connector.—This "Nobolt" bus connector, developed by the Sheldon Service Corp., Long Island City, N. Y., employs a new principle in joining tubular buses. As indicated by the name, it has no bolts, but works through internal expansion wedges to obtain high pressure contacts on tubing. Wedges are self-locking to prevent loosening due to vibration. Locked, the connector withstands a 3-ton pullout. A furnished tapered key and a hammer are the only tools necessary to make or break connections. The outside diameter of the connector is the same as the tubing, making insulation simple. These connectors are available in all shapes and sizes from $\frac{3}{4}$ inch sps. up.





Lamp Dimmer.—An improved device for controlling lamp brilliancy, known as the "Autrastat Dimmer", has been introduced by the Ward Leonard Electric Co., Mount Vernon, N. Y. It provides a smooth, flickerless dimming, permits greater flexibility in loading, and operates at high efficency. The device has the characteristics of an autotransformer with an infinite number of steps, and its low losses result in a minimum amount of heat dissipation. It will control any load from a 10-watt lamp up to the maximum rating of the dimmer with equal facility and the same rate of change in intensity. At any dimmer position, the connected load may be increased or decreased without affecting the intensity. These dimmers are available in 3 sizes—up to 6,000-watts maximum capacity.

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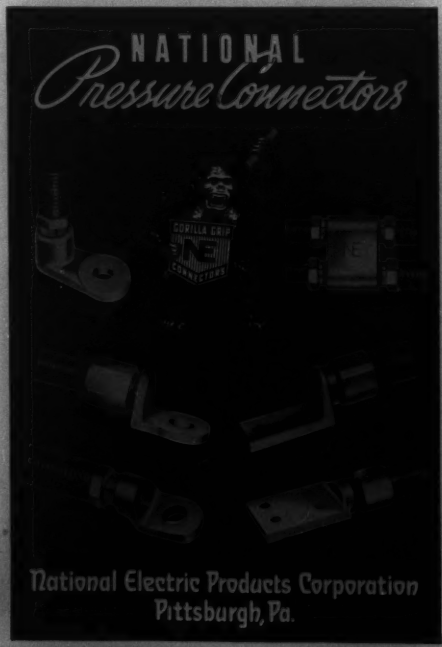

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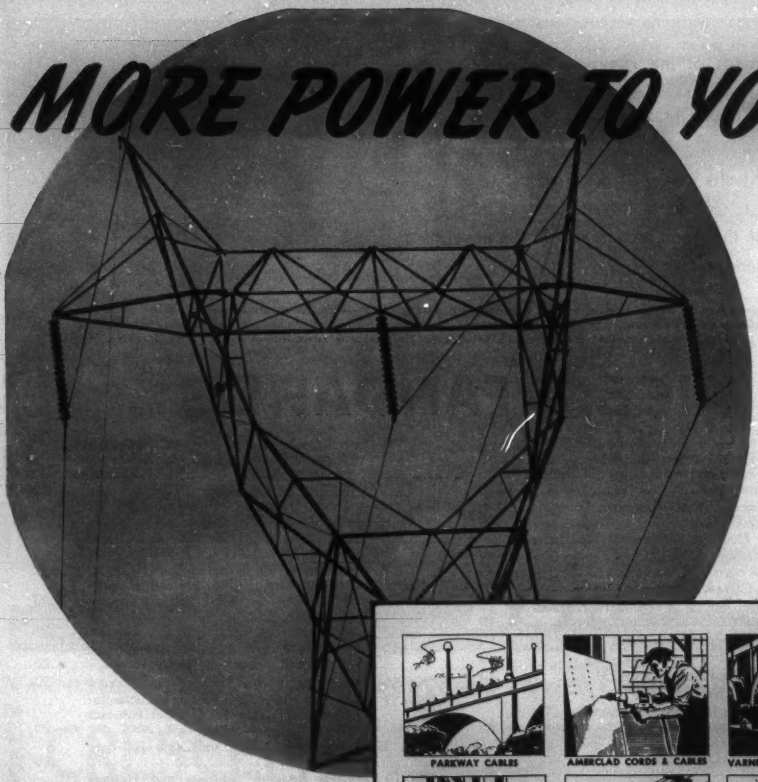

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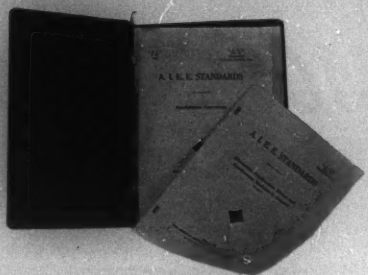

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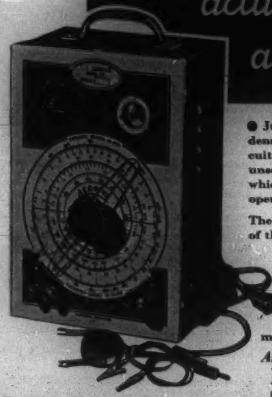

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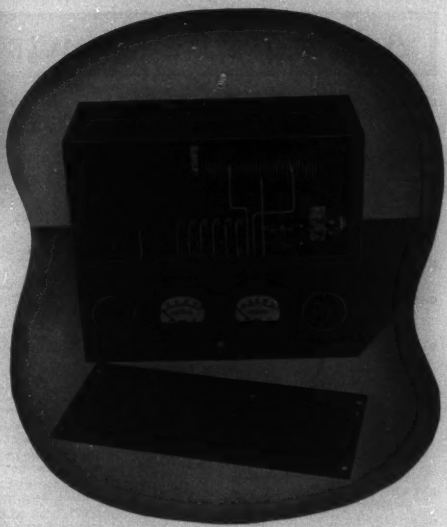

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INSULATING MATERIALS

Cloth

General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago

Compounds

General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago
National Elec. Products Corp., Pittsburgh
Roebling's Sons Co., John A., Trenton, N. J.

Moulded

General Electric Co., Bridgeport, Conn.

Paper

General Electric Co., Bridgeport, Conn.

Porcelain

Universal Clay Products Co., Sandusky, O

Tape, Friction

Minerallac Electric Co., Chicago
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N.J.

Varnishes

General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago

INSULATORS, PORCELAIN
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
National Elec. Products Corp., Pittsburgh
Universal Clay Products Co., Sandusky, O.

LIGHTING EQUIPMENT, OUTDOOR
General Electric Co., Schenectady, N. Y.

LIGHTNING ARRESTERS
General Electric Co., Schenectady, N. Y.

LOAD RECORDERS—CONTROLLERS
Leeds & Northrup Co., Philadelphia

LOCOMOTIVES, ELECTRIC
General Electric Co., Schenectady, N. Y.

METERS, ELECTRICAL
(See INSTRUMENTS, ELECTRICAL)

MOTORS
(See GENERATORS AND MOTORS)

PENCILS, DRAWING
Dixon Crucible Co., J., Jersey City, N. J.

PLASTIC PRODUCTS
General Electric Co., Schenectady, N. Y.

POLE LINE HARDWARE
Malleable Iron Fittings Co., Branford, Conn.
Ohio Brass Co., Mansfield, O.

POLE MOUNTS
Malleable Iron Fittings Co., Branford, Conn.

PORCELAIN, ELECTRIC
Universal Clay Products Co., Sandusky, O.

RECTIFIERS
General Electric Co., Schenectady, N. Y.
International Telephone Dev. Co., Inc., N. Y.

REGULATORS, VOLTAGE
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Sola Electric Co., Chicago, Ill.

RELAYS
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Weston Elec. Instrument Corp., Newark, N.J.

RESISTORS
Aerovox Corp., New Bedford, Mass.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago

RHEOSTATS, LABORATORY
General Electric Co., Schenectady, N. Y.
International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago

STEEL, ELECTRICAL
Carnegie-Illinois Steel Corp., Pittsburgh

SUB-STATIONS
General Electric Co., Schenectady, N. Y.

SURGE ABSORBERS
Ferranti Electric, Inc., New York

SWITCHBOARDS
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.

SWITCHES, AUTOMATIC TIME
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago

SWITCHES, DISCONNECT
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., Bethlehem, Pa.

SWITCHES, GENERATOR FIELD
I-T-E Circuit Breaker Co., Philadelphia

TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh

TRANSFORMERS
Acme Elec. & Mfg. Co., Cuba, N. Y.
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Kuhlman Electric Co., Bay City, Mich.
Sola Electric Co., Chicago

TURBINE GENERATORS
General Electric Co., Schenectady, N. Y.

TURBINES
General Electric Co., Schenectady, N. Y.

WELDERS, ARC
General Electric Co., Schenectady, N. Y.

WELDING WIRE
American Steel & Wire Co., Cleveland, O.
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N.J.

WIRES AND CABLES

Aluminum

Aluminum Co. of America, Pittsburgh

Armored Cable

American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Asbestos Covered

American Steel & Wire Co., Cleveland, O.
General Cable Corp., New York
General Electric Co., Bridgeport, Conn.
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N.J.

Bare Copper

American Steel & Wire Co., Cleveland, O.
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
National Elec. Products Corp., Pittsburgh
Roebling's Sons Co., John A., Trenton, N. J.

Bronze

Copperweld Steel Co., Glassport, Pa.

Copper Covered Steel

American Steel & Wire Co., Cleveland, O.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York

Flexible Cord

American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Heavy Duty Cord

American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Lead Covered (Paper and Var. Cambric Ins.)

American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Magnet

American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

Rubber Insulated

American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton N. J.

Tree Wire

American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

Weatherproof

American Steel & Wire Co., Cleveland, O.
Crescent Ins. Wire & Cable Co., Trenton, N.J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
National Elec. Products Corp., Pittsburgh
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.

X-RAY UNITS, INDUSTRIAL
General Electric X-ray Corp., Chicago, Ill.

A NATION UNITED BY TELEPHONE

JUST twenty-five years ago, on January 25, 1915, the first transcontinental telephone call was made. East and West were united in dramatic ceremony.

President Wilson talked from the White House across the country, testifying to the nation's pride "that this vital cord should have been stretched across America as a sample of our energy and enterprise."

The inventor of the telephone, Alexander Graham Bell, in New York, repeated across the continent to San Francisco the first words ever heard over a telephone—"Mr. Watson, come here, I want you"—to the same Thomas A. Watson who had heard them in the garret workshop in Boston in 1876.

That ceremony ushered in transcontinental service twenty-five years ago. At that time it cost $20.70 to call San Francisco from New York. Now it costs $6.50 for a station-to-station call and only $4.25 after seven in the evening and all day Sunday.

In 1915 it took about half an hour, on the average, to make a connection. Now most calls are put through without hanging up.

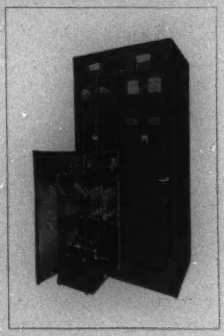
These are measures of progress in the never-ending effort of the Bell System to give faster, clearer, more useful and courteous service to the people of the United States.

. . .

BELL TELEPHONE SYSTEM

METAL-CLAD SWITCHGEAR—*by Roller-Smith*

MODERATE DUTY VERTICAL LIFT



HERE is a development by Roller-Smith to meet the call for adequate and economical control of generators and distribution facilities of central stations, industrial plants, office buildings, hospitals and similar institutions—with services of 5,000 volts or less at interrupting capacities of 25,000 and 50,000 KVA.

Engineers will be interested in the features of flexibility to meet, exactly, a wide variety of standard conditions and its easy adaption to special requirements. These are fully presented in the new Roller-Smith Catalog AE 8-b.

This special catalog gives illustrations, dimensional data, circuit arrangements and full specifications for indoor services.

Send for your copy of NEW Catalog AE 8-b

ROLLER-SMITH COMPANY
Electrical Measuring and Protective Apparatus

MAIN OFFICE and WORKS BETHLEHEM, PA., U. S. A.

SALES AGENCIES IN PRINCIPAL CITIES IN UNITED STATES AND CANADA

ROWAN CONTROL
THE ROWAN CONTROLLER CO., BALTIMORE, MD.

Motor control can be supplied, mounted and ready to wire. Send us your specifications.

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EXTRA **National Power News** EXTRA

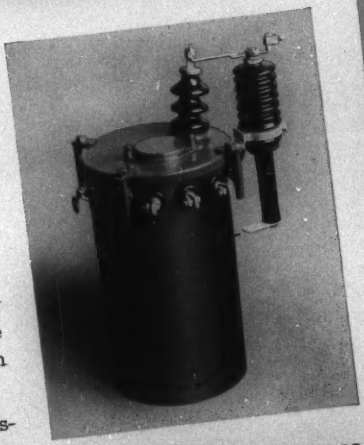
REMARKABLE FOUR-YEAR SERVICE RECORD ESTABLISHED BY KUHLMAN C.S.P. TRANSFORMERS

In the four years that they have been in active service, Kuhlman C.S.P. transformers have established a remarkable record for efficient performance. Today, more than ever before, informed utility men in need of C.S.P. transformers are specifying Kuhlman.

Kuhlman C.S.P. transformers avoid service interruptions and thus eliminate costly load surveys by automatically lighting a warning signal. They provide complete protection against lightning, burnouts from short circuits and overloads.

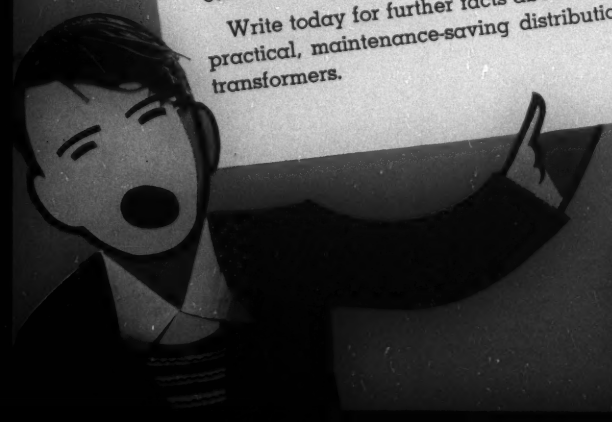
By relying on Kuhlman C.S.P. transformers for rural or suburban installations, you can assure more dependable service for your customers and lower maintenance costs for your plant.

Write today for further facts about these practical, maintenance-saving distribution transformers.



LOOK AT THESE FEATURES

Protection against lightning.
Protection against short circuit and overload burnouts.
Protection against service interruptions from fuse outages.
Low cost installation and maintenance.



KUHLMAN
ELECTRIC COMPANY
BAY CITY, MICHIGAN

The Basis of OKONITE QUALITY

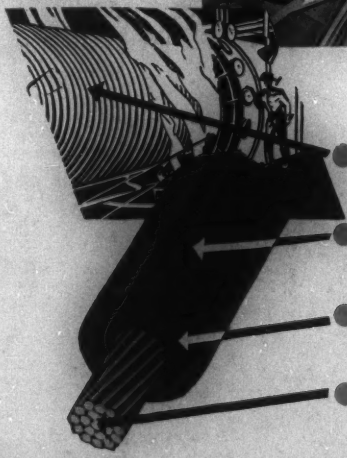
One or more similar machines applying inner strips of rubber insulation.

Final strip backed with sheet tin in position to form outer layer.

Shoe for forming and guiding final tin-backed strip about partially covered conductor.

Wheels compressing all layers into a solid, perfectly rounded mass. These wheels also lock final strip about conductor, thus forming the sheet tin backing into a continuous metal mold, which is removed after vulcanization.

Removing excess rubber but leaving familiar Okonite ridge.



Vulcanized in a continuous metal mold.

Distinguished by the familiar ridge known to the entire industry.

Dense uniform wall of Okonite rubber insulation.

Perfectly centered conductor.

THE OKONITE COMPANY

Founded 1878

EXECUTIVE OFFICE: PASSAIC, NEW JERSEY

HAZARD INSULATED WIRE WORKS DIVISION — THE OKONITE-CALLENDER CABLE CO., INC.

New York · Boston · Seattle · Buffalo · Chicago · Dallas · Detroit · Atlanta
Philadelphia · Los Angeles · Pittsburgh · Cleveland · St. Louis · Washington · San Francisco

OKONITE QUALITY CANNOT BE WRITTEN INTO A SPECIFICATION